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Hadron Physics at COSY
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Hadron Physics at COSY

Workshop Program

July 7 – 10, 2003

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1 Foreword

COSY allows the study of reactions with (un)polarized proton and deuteron beams up to momenta of about 3.88 GeV/c. The goal of the workshop *Hadron Physics at COSY* was to bring together experimentalists and theoreticians from various fields of hadron physics to identify the key physics questions, which can be addressed with proton and deuteron induced reactions at COSY. Recent reviews on the subject can be found in Refs. [1, 2]. The possibilities of approaching particular problems with hadronic probes were discussed.

These Miniproceedings are meant to present a useful collection of key references to the field as well as short summaries of the presentations[1]. For most of the talks the corresponding transparencies can be found on our home page under program/talks (http://www.fz-juelich.de/ikp/theorie/hpc2003/).

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[1] The speakers were asked for a one/two page summary for a parallel/overview talk.

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3 Opening session

3.1 Overview and Highlights of COSY

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The Cooler Synchrotron COSY [1] delivers polarized and unpolarized phasespace cooled proton- and deuteron-beams in the momentum range between 300 - 3650 MeV/c for internal as well as external experimental installations. The physics studied at the different experiments includes a variety of topics which are mostly covered by dedicated contributions to these proceedings.

A few recent results from experiments at COSY ranging from elementary pp interactions up to reactions on nuclei are briefly discussed, clearly demonstrating the high-performance detection capabilities of the experimental installations which allow in combination with the low emittance COSY beam for high-precision data.

The elastic pp scattering studies at EDDA [2] resulted in accurate data for excitation functions [3], analyzing power[4] and spin correlation parameters[5] which extend drastically the data base for phase shift analysis and improve the understanding of the elementary pp interaction. No hint was found for dibaryons which couple to NN.

The study of deuteron breakup performed at ANKE [6] probes the short range NN dynamics. The use of the CD Bonn potential including a rather soft short range NN potential gives a much better description of the data compared to RSC or Paris potentials [7].

High statistics η production has been performed at both the COSY-11 [8] and the TOF [9] installation from which background free differential distributions could be extracted. The distribution of the proton-proton invariant mass m_{pp} shows a drastic enhancement over the expected s-wave phase space distribution with pp FSI. A simple incoherent additional p-η FSI contribution is much too weak to account for this effect. Higher partial waves in the pp-system might explain the

enhancement [10] and additionally a coherent inclusion of pp and p-η FSI seems to be necessary. The measurement of spin correlation parameters would clarify this point. First investigations of η production with a polarized beam [11] result in a rough determination of the angular distribution of the analyzing power. The analysis of a higher statistics data sample will allow to disentangle the dominant contributing exchange mesons in the production (π, η [12] or ρ [13]).

The hyperon production performed at TOF[14] and COSY-11 [15] [16] yield very informative and surprising results. The geometrical decay spectrometer at TOF allows a nearly background free sample of Λ events. In Dalitz plots for beam momenta of 2.95 and 3.2 GeV/c the excitation of nucleon resonances as well as the p-Λ FSI are clearly visible. A comparison of the data with the resonance model [18] including a coherent addition of N^* excitation and p-Λ FSI shows a strong dominance of the $N^*(1650)$ at 2.95 GeV/c and equal contributions from $N^*(1650)$ and $N^*(1720)$ at 3.2 GeV/c. The most actual result at COSY-11 [16], the extreme high cross section ratio between Λ and Σ production close to threshold with a value of about 28 compared to the factor 2.5 at high energies, is still not unambiuously explained. Several very different models with only π and K exchange, coherently or incoherently added, additional exchange mesons with or without intermediate N^* excitation are able to at least describe the trend of the data within a factor of two [17]. A solid data base for Y-N data is really missing which would allow to fix more parameters for the model descriptions.

The K^+ production in nuclei far below the free NN production threshold performed at ANKE [19] addresses topics like medium modification, reaction mechanism and collectivity. The K^+ potential in nuclei could be determined from the comparison of the cross section ratio between different nuclei (Au/C) with model calculations by varying the potential depth. A value of 20 $\pm$3 MeV results whereby compared to relativistic heavy ion collisions the potential is determined at normal nuclear density. Another interesting aspect in the K^+ production studies are the K^+-d correlations [20] which yield informations on the production mechanism. From a first test run at 1.2 GeV it is estimated that about 30 % of the productions is

mediated by a two step mechanism ($pN \to d\pi$, $\pi N \to K^+\Lambda$).

Much more highlights and results are available which can not be presented within this short overview. Not even all experimental installations were covered by the selected topics.

The near future physics program at COSY will certainly continue the present activities. Several results answered some but opened new questions as well which need more selective studies by a full control of the spin and isospin degrees of freedom. Furthermore new topics will be included which were in a large part presented during this workshop.

A main point in the future must be an additional detection capability for photons which will drastically improve the performance for present investigations but mainly will open new possibilities. Concerning e.g. the η production an additionally detection of photons would allow to remove the unavoidable background in missing mass measurements by a tag on the $\eta \to \gamma\gamma$ decay. Only the precise measurement of both charged and neutral particles will give the opportunity to separate overlapping structures like the important but not fully understood $\Lambda(1405)$ and the $\Sigma(1385)$. Further, production studies with more than one neutral ejectile will only be possible with a 4 π charged and neutral particle detector, and will guarantee an active, topical and exciting future at COSY.

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3.2 Aspects of NN induced Reactions

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The goal of this presentation is to introduce the audience to the opportunities and challenges of studying NN induced reactions.

As an example, the steps necessary to extract in a controlled way the Λ–nucleon scattering lengths from the invariant mass spectrum of the reaction $pp \to pK^+\Lambda$ were discussed in detail: first of all a Dalitz plot analysis is necessary to prove, that the structure in the spectrum actually stems for the hyperon–nucleon interaction. Although in a large momentum transfer reaction the production operator itself should not introduce any significant energy dependence, the occurrence of resonances and their interference with final state interaction effects might well distort the signal [2]. In the next step polarization observables are to be used to disentangle the possible spin states. Once this is done the scattering lengths can be extracted from the data directly [1].

As an additional illustration of the potential of polarization observables, the use of double polarization observables as spin filters was discussed. For details we refer to Ref. [3].

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[3] C. Hanhart, submitted to Physics Reports.

4 Charge symmetry breaking

Convenors: H. Machner and J. Niskanen

4.1 Charge Symmetry Breaking-2003

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Charge symmetry is the invariance of the QCD Lagrangian under the interchange of u and d quarks, if one makes the reasonable assumption that the masses these two light quarks are the same[1]. In isospin space, this is invariance under rotations of 90° about the y axis. This is to be contrasted with isospin symmetry which is invariance under arbitrary rotations[2].

Charge symmetry breaking CSB arises only from the mass difference between the u and d quarks and from electromagnetic effects[1]. The quark origin of the effects offers the special opportunity to examine the direct influence of quarks in hadronic physics. The positive nature of $m_d - m_u$ causes the neutron to be more massive than the proton which gives the hydrogen atom its stability and causes the sun to shine.

CSB in the nucleon-nucleon system causes the scattering length a_{nn} to be more negative than a_{pp} and a positive value of the difference neutron and proton analyzing powers at the (non-zero) angle at which the analyzing power goes through zero[3]. This establishes the existence of class III and IV potentials[4]. The use of a NN potential that reproduces the scattering length difference leads to an explanation of the Okamoto-Nolen-Schiffer anomaly[1, 5] (within 10-20%) in heavy nuclei.

A new era in studies of CSB was initiated by studies of effective chiral Lagrangians in which QCD is mapped onto onto a chiral Lagrangian that respects chiral symmetry[6]. This leads to terms of the form $N^\dagger \pi_3 \boldsymbol{\tau} \cdot \boldsymbol{\pi} N$ and $N^\dagger \tau_3 \pi^2 N$ that cause charge symmetry to be severely violated in π^0 interactions with nucleons. Thus it is worthwhile to examine CSB in pion production processes[7]. Hence the

new striking observations of CSB in the reactions $np \to d\pi^0$[8] and $dd \to \alpha\pi^0$[9] are particularly exciting. A consortion of theorists including: A. Fonseca, A. Gardestig, C. Hanhart, C. J. Horowitz, G. A. Miller, A. Nogga and U. van Kolck has been formed to compute the cross section for the $dd \to \alpha\pi^0$ reaction. C. Hanhart and J. Niskanen are recomputing the forward-backward asymmetry for the reaction $np \to d\pi^0$. These new experiments and the related studies planned at COSY will provide new insights into the role of the light quark mass difference in hadronic physics and into the origin of mass.

I thank the USDOE for partial support of this work.

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4.2 Isospin Symmetry breaking studies at GEM

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The concept of isospin symmetry was introduced already in the thirties into subatomic physics. Heisenberg [1] assumed the neutron soon after its discovery and the proton to be two different states of the otherwise identical nucleon. He introduced a variable τ, the isotopic spin in order to distinguish neutrons and protons. Breit et al. and Cassen et al. [2] claimed the strong part of nucleon-nucleon s-wave interactions to be almost independent from isotopic spin. The latest summary with these physics input is Ref. [3]. Isospin symmetry breaking was assumed to occur only via the Coulomb force. The next summary [4] took differences between up and quark masses into account. On the level of quarks isospin symmetry is broken by

$$\frac{m_u - m_d}{m_u + m_d} \approx -0.3 \tag{1}$$

Here we have used the current masses of the quarks. However, in experiments we are dealing with real mesons and the isospin symmetry violation effects can be estimated from their masses. Quarks mass differences can be estimated from

$$\frac{m(K^0) - m(K^+)}{m(\omega)} = 0.0051 \tag{2}$$

with the ω mass as a typical hadron mass. The mass difference between pions is believed to be almost only due to Coulombian forces thus

$$\frac{m(\pi^+) - m(K^0)}{m(\omega)} = 0.0059. \tag{3}$$

Both effects seem to be of the same order of magnitude. The first effect leads to $\pi^0 - \eta$ mixing. In principle also the mixing with η' has to be included but is believed to be small. Following a conjecture by C. Y. Yang we compare cross sections for pion production in pp and np reaction [5, 6]. Isospin violation is found in close to threshold values for the total spin and at $\eta \approx 0.5$ for the anisotropy. In pion production in $pd \to (A = 3) + \pi$ we found angular distributions to consist of two

components: one coherent part which violates isospin symmetry and an isotropic incoherent part which obeys isospin symmetry to a high degree [7, 8]. The latter shows deviation from isospin symmetry in the vicinity of the η-threshold [9].

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4.3 The isospin forbidden $dd \rightarrow {}^4He\pi^0$ reaction near threshold

E. Stephenson[2]

[2] E. Stephenson could not come to Bad Honnef. The essence of the talk was presented by A. Opper in front of her presentation.

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The results on the total cross section for the $d + d \to^4 He\pi^0$ reaction have been accepted for publication by Physical Review Letters. A preprint may be found in Ref. [1]. A review of the chiral Lagrangians is contained in Ref. [2]. The cross sections are normalized against the work on dp elastic scattering from the KVI that is now available in Ref. [3].

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4.4 CSB in forward–backward Asymmetry in $pn \to d\pi^0$

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4.5 Search for $\pi^0 - \eta$ mixing

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On the quark level the isospin symmetry is broken due to the u and d quarks current mass difference and their electroweak interaction. In some part this quark mass difference is responsible for the hadron mass difference. This effect can be partially described in the chiral perturbation theory or in the lattice calculations which lead to an estimation of the u and d quark mass ratio or their average mass (see Ref. [1] for review). Beside this the dynamical effects in the strong hadron

interaction are induced by the quark mass difference and one of the most important is the light meson mixing. Such effects can be calculated perturbatively and may be directly related to the quark mass difference. On the other hand the mixing may be also easily studied experimentally via the isospin or charge symmetry breaking processes. The strength of the isospin or charge symmetry breaking depends on the mixing angle θ_m. Magnitude of this angle plays an important role in various processes where pions appear in the intermediate or final states (e.g. in the analysis of CP violation sources [3, 4] or in the analysis of $B \to \pi\pi$ decays [5]). Various QCD based models predict the $\pi^0 - \eta$ mixing angle in the range of 0.014-0.015 rad (see [6] for references). Experimental evidence comes from isospin or charge symmetry forbidden meson decays (see [7] for references). This mixing was also observed in hadronic reactions π^+d$\to$ppη and π^-d$\to$nnη, where the $\pi^0 - \eta$ mixing angle of 0.026$\pm$0.007 rad [8] was extracted.

The importance of the $\pi^0 - \eta$ meson mixing was predicted for the pd$\to^3$Hπ^+/^{3}Heπ^0 reactions [6]. The isospin symmetry predicts the ratio of the cross section for these reactions to be equal 2. Due to meson mixing the real π^0 meson have a small admixture of isospin 0, which leads to some deviation of this ratio. A large effect of isospin symmetry breaking due to meson mixing should appear for beam momenta close to the η meson production threshold and for outgoing products angles corresponding to large relative proton-pion angles. In order to extract the mixing angle, the beam momentum dependence of the ratio was measured for five beam momenta over a narrow region close to the η production threshold. In order to reduce the systematic uncertainty a simultaneous measurement was performed. Details on the experimental procedure and on data evaluation can be found in Refs. [9]. The ratio of the cross sections as well as the absolute values of the cross sections were obtained. The measured values of the cross sections ratio indicate the isospin symmetry breaking effects. The present data lead to the ratio values larger than 2 at beam momenta far above the η threshold. This may be due to systematical uncertainty of the data, however, it might be also attributed to isospin symmetry breaking effects not related to the meson mixing. The largest effect may originate from the differences in the wave functions of ^{3}H and ^{3}He nuclei [10]. The simple

model of Ref. [6] does not contain all the effects that may lead to a deviation of the cross sections ratio from the isospin symmetry predicted value of 2. When comparing the model predictions to the experimental results this effect as well as systematic uncertainty of the data were combined together and treated as an overall normalization factor N. In the fitting procedure the global minimum χ^2/n was found for N=1.15 and $\theta_m = 0.006 \pm 0.005$ rad. More details on the results and model analysis may be found in [11]. The analysis with more advanced model based on K-matrix formalism [12] might deliver more exact information on mixing angle.

Much better for the interpretation in terms of meson mixing will be the dd$\rightarrow{}^4$Heπ^0 reaction. When measured at the η production threshold, the cross section for this reaction is directly proportional to the θ_m^2 and the known cross section for dd$\rightarrow{}^4$Heη reaction. Such a measurement was proposed at the COSY accelerator [13]. The cross section for charge symmetry forbidden dd$\rightarrow{}^4$Heπ^0 reaction is expected to be very small [6]. Therefore the detection of all ejectiles is necessary in order to reduce background substantially. It would necessitate in the photon detector for measurements of the π^0 decay products. The construction of such detector is planned at COSY [14].

The charge symmetry breaking part of the nucleon-nucleon interaction induced by $\pi^0 - \eta$ mixing may be studied in pn$\rightarrow$dπ^0 reaction. The center of mass forward-backward asymmetry of the cross section have to be measured. It is proposed to study this reaction as a quasi-free reaction pd$\rightarrow$dπ^0p on the neutron in the deuteron. The advantage of such measurement is the simultaneous detection of pd$\rightarrow$dπ^+n reaction, what allows for continuous control of the systematic uncertainties. Even better will be the investigation of the asymmetry of the analyzing power when the polarized COSY proton beam is used. With the proton beam momentum of 750 MeV/c the measurement may be performed in the region where the analyzing power reaches maximum of -0.55 and the predicted asymmetry is largest. The advantage of the asymmetry investigation is that the measurement is relative and no acceptance corrections influence the final result. In order to unambiguously identify both quasi-

free reactions it is necessary to measure angle and energy of deuteron and proton (for pd→dπ^0p) or deuteron and π^+ (for pd→dπ^+n) and identify the deuteron. Such a measurement is possible with the Germanium Wall detector [15]. This detector with large angular acceptance, very good angular and energy resolution and the axial symmetry is ideally suited for such investigations with polarized beam.

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4.6 Charge symmetry breaking meson production

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Breaking of the isospin symmetry, in particular charge symmetry breaking, has been studied for a long time as the difference between the *pp* and *nn* systems and mirror nuclei. During the past decade the study has increasingly concentrated on the *np* interaction, where actual mixing of isospin values zero and one can take place. This makes it possible, for example, to produce pions also from the initial nuclear isospin zero component in $np \to d\pi^0$, which in turn can be observed as an asymmetry about 90° in the differential cross section [1]. Without an interference of the two isospin states the cross section would be symmetric.

Charge symmetry breaking is intimately related to the up- and down-quark mass difference in QCD (and also to the electromagnetic interaction). This effect has recently been explicitly incorporated as an isospin breaking effective pion-nucleon interaction in a calculation of $np \to d\pi^0$ close to threshold, and presently it appears to be the largest contribution so far discussed [2]. Another important contribution previously investigated is $\eta\pi$ meson mixing, which enters with the opposite sign [3], and so the two are qualitatively different. The TRIUMF experiment [1] gives the sign favouring the dominance of isospin breaking pion rescattering and will be discussed elsewhere in these proceedings.

This talk discusses theoretical consequences of the principal mechanisms mainly in mesonic inelasticities along with their uncertainties. Some connections to the more complex isospin forbidden reaction $dd \to {}^4\mathrm{He}\pi^0$ are presented.

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4.7 $a_0 - f_0$ mixing

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Regardless the efforts of recent years to resolve the nature of the light scalar resonances, no consensus is found up to date if they are predemonantly of $\bar{q}q$, $\bar{q}\bar{q}qq$ or molecular nature. It is expected, that the magnitude of the charge symmetry breaking (CSB) $a_0 - f_0$ mixing amplitude, predicted to be unusually large [1], will help to shed additional light on this important question.

In complete analogy to what was discussed e.g. by G.A. Miller at this conference, also the forward backward asymmetry in $pn \to d\pi\eta$ as well as $dd \to \alpha\pi\eta$ vanish in the absence of CSB and are thus clean experiments to quantify the $a_0 - f_0$ mixing [2]. The fact that a_0 and f_0 are rather narrow and overlapping (their nominal masses according to the particle data group differ by a few MeV only) in addition guarantees that the CSB are to be completely dominated by the mixing effects [3] and thus can be extracted even without detailed knowledge about the production operator. This is in vast contrast to the situation for pion production [4].

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4.8 Mixing of the pseudoscalar mesons

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The mixing parameters of the pseudoscalar meson states and their decay constants are calculated within QCD to first order of flavour symmetry breaking on exploiting the divergencies of the axial vector currents which embody the $U(1)_A$ anomaly. Starting point of this analysis is the quark flavour basis and the assumption that the decay constants in that basis follow the pattern of particle state mixing. The proposed mixing scheme is tested against experiment and corrections to the first order mixing parameters are determined phenomenologically. It also allows for an estimate of isospin violations for pseudoscalar mesons. It is found for instance that the η admixture to the π^0 amounts to 1.4%. The talk is based on Refs. [1, 2, 3].

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5 η Production

Convenors: P. Moskal and C. Hanhart

5.1 Eta production

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Results of the study of the ηpp dynamics presented in the talk are avaiable via the e-Print Archive server [1]. Here we abridged the text to few remarks – from the introduction of this article – concerning investigations of the interaction between the η meson and the proton.

Due to the short live time of the flavour-neutral mesons (eg. η or η'), the study of their interaction with nucleons or with other mesons is at present not feasible in direct scattering experiments. One of the methods permitting such investigations is the production of a meson in the nucleon-nucleon interaction close to the kinematical threshold or in kinematics regions where the outgoing particles possess small relative velocities. In the last decade major experimental [2, 3, 4] and theoretical [5, 6] efforts were concentrated on the study of the creation of η and η' mesons via the hadronic interactions [7]. Measurements have been performed in the vicinity of the kinematical threshold where only a few partial waves in both initial and final state are expected to contribute to the production process.

The determined energy dependences of the total cross section for η' [2, 3] and η [3, 4] mesons in proton-proton collisions reveals that the proton-proton FSI enhances the total cross section by more than an order of magnitude for low excess energies. Interestingly, in the case of the η meson the increase of the total cross section for very low and very high energies is much larger than expected from the $^1S_0$ final state interaction between protons. The excess at higher energies can be assigned to the significant onset of higher partial waves, and the influence of the attractive

interaction between the η meson and the proton could be a plausible explanation for the enhancement at threshold.

The interaction between particles depends on their relative momenta. Therefore it should show up as modification of the phase-space abundance in the kinematical regions where the outgoing particles possess small relative velocities. Only two invariant masses of the three subsystems are independent and therefore the entire accessible information about the final state interaction of the three-particle system can be presented in the form of the Dalitz plot. To some extent this information is still available from the projections of the phase space population onto the invariant mass distributions. These have been recently determined at Q = 15 MeV by the COSY-TOF collaboration [8] and at Q = 15.5 MeV by the COSY-11 group [1]. The structure of the observed spectra may indicate a non-negligible contribution from the P-waves in the outgoing proton-proton subsystem [6]. The amount of the P-wave admixture derived from the proton-proton invariant mass distribution leads to a good description of the excitation function at higher excess energies while at the same time it spoils significanly the agreement with the data at low values of Q [6]. In contrast to the P-wave contribution the three-body treatment [9] of the $pp\eta$ system leads to an even larger enhancement of the cross section near threshold than that based on the Ansatz of the factorization of the proton-proton and proton-η interactions. For the complete understanding of the low energy $pp\eta$ dynamics, a rigorous three-body approach to the $pp\eta$ system is required. A herald of such calculations have been already reported [9, 10].

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5.2 Potential of the COSY-11 facility

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One of the main goal of the COSY-11 collaboration is to study the eta meson interaction with nucleons and the mechanism of the η production in different isospin channels. Over the last few years, we have performed several experimental investigations on the close to treshold η production in nucleon-nucleon collisions using unpolarized as well as polarized beam. Experiments of the $pp \to pp\ \eta$, $pd \to pd\ \eta$ and $pn \to pn\ \eta$ are based on the four-momentum registration of outgoing nucleons and nuclei. η meson is identified via the missing mass technique.

The internal facility COSY-11 [1] installed at the Cooler Synchrotron COSY [2] is shown in the figure below.

Results of the performed measurements and the details of the experimental method can be found in references [3].

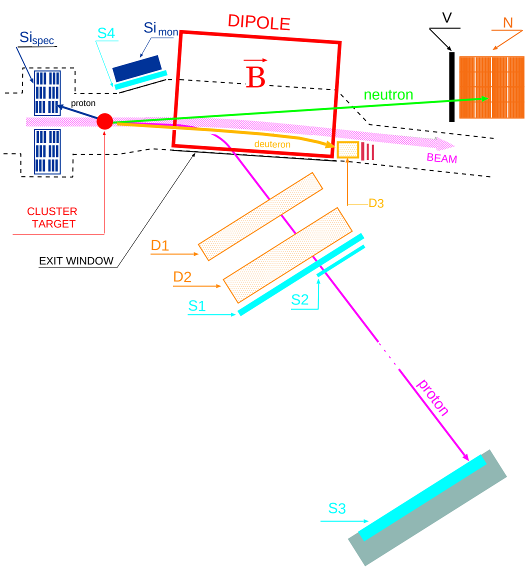

Figure 1: *Scheme of the COSY-11 detection system. Protons are registered in two drift chambers D1, D2 and in the scintillator hadoscopes S1, S2, S3. An array of silicon pad detectors (Si_{spec}) is used for the registration of the spectator protons. Neutrons are registered in the neutron modular detector(N). In order to distinguish neutrons from charged particles veto detector is used. Deuterons are registered in deuteron chamber D3.*

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5.3 Recent Results from TOF

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5.4 Higher Partial Waves in $pp \to pp\eta$

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It is shown that most of the available data on the $pp \to pp\eta$ reaction [1], including the invariant mass distributions in the $pp \to pp\eta$ reaction recently measured at COSY [2, 3], can be understood in terms of the partial-wave amplitudes involving final pp S and P states and the η meson s-wave. This finding, together with the fact that results within a meson–exchange model are especially sensitive to the details of the excitation mechanism of the $S_{11}(1535)$ resonance, demonstrates the possibility

of investigating the properties of this resonance in NN collisions. The spin correlation function C_{xx} is shown to disentangle the S- and P-wave contributions. It is also argued that spin correlations may be used to help constrain the contributions of the amplitudes corresponding to the final pp $^3P_0$ and $^3P_2$ states. Details of the present results may be found in Ref.[4].

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5.5 Three-body treatment of η production in pp-collision

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Effect of interaction between the final particles in the reaction $pp \to pp\eta$ is studied. The calculation is based on the three-body approach to the ηNN system as is

presented in [1]. Three-body theory being a natural theoretical frame for treating correctly the ηNN interaction provides reasonable quantitative explanation of the energy dependence of the total cross section measured for $pp \to \eta pp$ in the region of the c.m. excess energy $Q = 40$ MeV. The obtained results are however subject to correction because of Coulomb forces.

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5.6 The reaction $np \to \eta d$ near threshold

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The reaction $np \to \eta d$ has been measured recently in the region near threshold [1]. Since the cross section shows a strong enhancement at threshold, as compared with the predictions based on a two-body phase space, it has been speculated that this could be a signal for an ηNN quasibound state, predicted some time ago [2]. However, the solutions of the three-body equations for ηd elastic scattering do not support the existence of a ηNN quasibound state but rather indicate the presence of a quasivirtual state [3-5].

In Ref. [6] we constructed seven diferent separable-potential models (labeled 0 to 6) of the coupled ηN-πN-σN system in the S_{11} channel (the σ was taken as a stable particle with $m_\sigma = 2m_\pi$) by fitting the seven $\eta N \to \eta N$ amplitude analyses of Refs. [7-10] and the $\pi^- p \to \eta n$ cross section in the region of the S_{11} resonance. The main feature that distinguishes these models among themeselves is the value predicted for the real part of the ηN scattering length which runs from Re $a_{\eta N} = 0.42$ fm

for model 0 to Re $a_{\eta N} = 1.07$ fm for model 6. For the nucleon-nucleon interaction in the ${}^3S_1$ channel we used the rank-1 separable potential [11] that generates the same deuteron wave function as the Paris potential (so-called PEST potential). We found that the quasivirtual state moves closer and closer to the real axis when the ηN interaction gets stronger, i.e., when Re $a_{\eta N}$ becomes larger [5]. The pole moves from $q = -0.29 - i0.44$ fm to $q = -0.06 - i0.16$ fm when one goes from model 0 to model 6. The fact that the pole lies in the third quadrant of the momentum plane means that it lies in the second Riemann sheet of the energy plane.

We calculated the $np \to \eta d$ cross section using the three-body formalism described above. We found that the shape of the $np \to \eta d$ cross section within a wide energy range can only be explained by an ηN interaction model corresponding to a small scattering length (e.g. the Jülich model [7]) and this is independent of the meson production mechanism considered.

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5.7 Spin Observables in Meson Production in NN Collisions

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Spin observables are very useful probes of the NN interaction. This talk describes advantages of using both polarized beam and target to access variety of single and double spin observables. The experimental technique of kinematically complete $\vec{p}\,\vec{p} \rightarrow pp\pi^0$ and $\vec{p}\,\vec{p} \rightarrow p\pi^+$ measurement are given. The significance of higher partial waves for meson production above threshold is shown on the example of ϕ-independent $\Delta\sigma_L$ and $\Delta\sigma_T$. For inclusive π measurements the various ϕ-distribution are key to disentangle single (A_y) and double (C_{xx}, C_{yy}, C_{xy}) spin observables. From 3 independent ratios of ϕ-dependent yields $N_{++}, N_{+-}, N_{-+}, N_{--}$, one can extract uniquely the observables.

Simultaneous measurement of directions of two outgoing particles allows for determination of more exotic single spin observable $A_z(\Delta\phi)$.

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5.8 Double Polarized Observables at ANKE

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The study of near–threshold meson production in *pp* collisions involving polarized beams and polarized targets offers the rare opportunity to gain insight into short–range features of the nucleon–nucleon interaction. The Cooler Synchrotron

COSY at FZ–Jülich is a unique environment to perform such studies. Ideally, measurements of polarization observables require a cylindrically symmetrical detector, capable to measure the momenta and the directions of outgoing charged hadrons.

In the case of the reaction $\vec{p}\vec{p} \to ppn$, a measurement of some polarization observables seems feasible using the ANKE magnetic dipole spectrometer in the Q-range of a few ten MeV. If one assumes a purely vertically polarized beam ($P_x = P_z = 0$) and a purely vertically polarized target ($Q_x = Q_z = 0$), the spin-dependent cross section reads after integration over the relative momenta $\vec{k}_{NN}$

$$\begin{aligned}\sigma/\sigma_0 = 1 \quad &+ \quad A_y^B \cdot P_y \cdot \cos(\phi) + A_y^T \cdot Q_y \cdot \cos(\phi) \\ &+ \quad \frac{1}{2}(A_{xx} + A_{yy}) \cdot P_y \cdot Q_y \\ &+ \quad \frac{1}{2}(A_{xx} - A_{yy}) \cdot P_y \cdot Q_y \cdot \cos(2\phi) \ ,\end{aligned}$$

where σ_0 is the spin-independent cross section and ϕ corresponds to the azimuth of the emitted η meson [1]. The azimuthal acceptance of ANKE near $\phi = 180^\circ$ ($\cos(\phi) = -1$, $\cos(2\phi) = 1$) together with identical beam and target particles ($A_y^T = A_y^B = A_y$) leads to a further simplification. The relative luminosity could either be measured from inclusive protons scattered near 0° or from pp elastic scattering. Beam and target polarizations could be determined from known analyzing powers of pp elastic scattering. Thus at $\phi = 180^\circ$ a measurement of A_y, A_{xx} would be possible. At any ϕ, a measurement of A_y, $A_\Sigma = A_{xx} + A_{yy}$ and $A_\Delta = A_{xx} - A_{yy}$ seems feasible.

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6 Vector Mesons

Convenor: M. Hartmann and A. Wirzba

6.1 Vector meson production - an overview

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Vector meson production in nucleon-nucleon collisions is an important tool in the study of the nucleon-nucleon interaction at short range. With masses in the range of 760 MeV for the isovector ρ and 780 MeV for the isoscalar ω, whose quark content is dominantly $u\bar{u} \oplus d\bar{d}$ while the $s\bar{s}$ is contained in the ϕ with 1020 MeV, these mesons are easily produced at COSY.

Early studies of pion-induced ω production on nucleons [1],[2] showed an exotic behavior of the reaction amplitude near threshold. Recently, this has been attributed to the contributions of resonances in the production of ω mesons [3] and [4] pointed out the importance of resonances and demonstrated that they may account for differences between ω and ϕ production.

Vector meson production in nucleon-nucleon collisions has gained increasing interest in recent years. Several experiments at Saturne have addressed ω (SPESIII [5], DISTO [6], [8]) as well as ϕ and ρ^0 production [7], [9] in proton-proton collisions. Early theoretical work discussed these cross sections and earlier measurements at higher excess energies [10] in the meson exchange framework [11], [12], [13]. Very detailed calculations have focussed on the near-threshold behavior of the cross section but fail to reproduce the excitation function at higher energies [14], [15], [16]. A recent measurement of TOF at COSY [17] closed the gap between 30 and 300 MeV in excess energy not covered by the Saturne experiments. The total cross sections confirm the overall trend and magnitude of the earlier data. The angular

distribution of the ω mesons in the overall center-of-momentum system is fairly anisotropic at $\epsilon = 173$ MeV in line with the DISTO data at 300 MeV, which indicates a dominant production through nucleonic currents. This is however at variance with the DISTO findings in the pp→ppϕ channel which is perfectly isotropic at about 90 MeV excess energy. Meanwhile, very detailed theoretical analyses of the pp→ppω data are available [18] which allow predictions to be tested in future COSY experiments. These calculations also demonstrate the importance of resonance contributions, but a quantitative analysis will need a much larger body of data. In particular, additional differential observables such as spectra of invariant masses in two-body subsystems will provide a valuable test of the model predictions. Additional measurements at the TOF spectrometer are under way (see talk of M. Schulte-Wissermann), other COSY experiments study the production of ω mesons also in other isospin channels such as pn→dω (see talks of I. Lehmann and M. Hartmann, [19]).

Vector meson production in bound systems has only been studied in very few experiments but exhibits very interesting features. The pd→^{3}Heω reaction was studied in an inclusive experiment at very backward ω angles only [20]. The extraction of the exitation function of the reaction amplitudes assumed isotropic angular distributions. This is one possible explanation for the steep fall-off of the amplitudes near threshold, but other explanations such as interactions of the decay pions with the nucleus or the influence of resonances are not ruled out. An exploratory measurement at the COSY-TOF spectrometer has demonstrated the feasibility of experiments covering the full ^{3}He angular distribution in coincidence with the charged pions from ω decay. These data will clarify the situation greatly. They can also be compared to exclusive measurements of ϕ production cross sections in pd fusion which were performed with the MOMO setup at the Big Karl spectrometer at COSY [21].

In summary, vector meson production is an inportant tool in the investigation of nucleon-nucleon interactions. The production of vector mesons with hadroninc probes on nucleons and nuclei yields information complementary to other experi-

mental approaches. COSY gives access to many degrees of freedom which have not been adequately explored to date.

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6.2 Vector Meson Production in NN Collisions

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Using a relativistic effective Lagrangian at the hadronic level, near-threshold ω and ϕ meson productions in proton proton (pp) collisions, $pp \to pp\omega/\phi$, are studied within the distorted wave Born approximation [1]. Both initial and final state pp interactions are included. In addition to total cross section data [2, 3, 4], both ω and ϕ angular distribution data [3, 4] are used to constrain further the model parameters. For the $pp \to pp\omega$ reaction we consider two different possibilities: with and without the inclusion of nucleon resonances. The nucleon resonances are included in a way to be consistent with the $\pi^- p \to \omega n$ reaction. It is shown that the inclusion of nucleon resonances can describe the data better overall than without their inclusion. However, the SATURNE data in the range of excess energies $Q < 31$ MeV are still underestimated by about a factor of two. As for the $pp \to pp\phi$ reaction it is found that the presently limited available data from DISTO can be reproduced by four sets of values for the vector and tensor ϕNN coupling constants. Further measurements of the energy dependence of the total cross section near threshold energies should help to constrain better the ϕNN coupling constant.

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6.3 The production of massive photons in meson-baryon interactions

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We consider the $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ reactions below and in the vicinity of the ρ^0- and ω-meson thresholds. Using the Vector Meson Dominance (VMD) assumption, the amplitudes describing these processes are related to the meson-nucleon amplitudes $\pi N \to V N$ and $V N \to V N$, where V stands for ρ^0- and ω-mesons [1-3]. We restrict our discussion to e^+e^- pair invariant masses ranging from 0.4 to 0.8 GeV. In these kinematics, the production of e^+e^- pairs off proton and neutron targets is closely linked to the coupling of vector mesons to low-lying baryon resonances. The $\pi N \to e^+e^-N$ reaction is determined by the $\pi N \to \rho^0 N$ and $\pi N \to \omega N$ amplitudes. In addition to the photoproduction of vector mesons materializing into e^+e^- pairs, the $\gamma N \to e^+e^-N$ reaction involves a large contribution from the production of e^+e^- pairs through the Bethe-Heitler

process. The dynamics of the $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ reactions reflects in quantum interference patterns. Both reaction cross sections are sensitive to ρ^0-ω interferences. The quantum interference between vector meson e^+e^- decays and Bethe-Heitler pair production plays also an important role in determining the $\gamma N \to e^+e^-N$ cross section.

We have calculated consistently the $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ reactions [2,3] in the framework of a recent relativistic and unitary coupled-channel approach to meson-nucleon scattering [1]. The study of the $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ reactions aims principally at gaining understanding of the structure of the $\pi N \to \rho^0 N$, $\pi N \to \omega N$, $\gamma N \to \rho^0 N$ and $\gamma N \to \omega N$ amplitudes arising from the presence of baryon resonances in this energy range and reflected in e^+e^- pair spectra. Measurements of the $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ cross sections, planned at GSI and JLab, will therefore shed light on the role of baryon resonances in these processes and be sensitive to their couplings to vector meson nucleon channels.

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6.4 Vector meson production with the DISTO spectrometer

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Angular distributions for vector meson production have been proposed [1] as a sensitive observable to extract the strength of nucleonic and mesonic currents respon-

sible in meson exchange models for the vector meson production near the threshold. Therefore, it is particularly interesting for various reaction models to compare the differential cross sections for the production of ρ^0, ω and ϕ mesons. In addition, total and differential cross sections are important for the understanding of OZI rule violations and the interpretation of dilepton spectra and the question of in-medium modifications of hadrons.

With the DISTO spectrometer [2] we measured the production of light vector mesons in the $pp \rightarrow ppX$ reaction at 3.67 GeV/c [3, 4] with the decay $\rho(\omega) \rightarrow \pi^+\pi^-(\pi^0)$ and $\phi \rightarrow K^+K^-$. Momentum reconstruction has been done with multi wire proportional chambers and a magnetic dipole field, particle identification with water Čerenkov detectors. A model independent acceptance correction has been applied. The angular distribution for ρ^0 production exhibits strong forward peaking, suggesting a dominance of the nucleonic current. The angular distribution for ω production at this beam energy is showing strong nucleonic contribution, too, but also an additional isotropic component signaling the importance of the mesonic $\pi\rho \rightarrow \omega$ fusion [1]. The total cross section of $\sigma_\rho = (23.4 \pm 0.8 \pm 8)\mu b$ with statistical and systematic errors, respectively, was determined by normalizing the acceptance corrected ρ^0 yield to the simultaneously measured exclusive η yield. For ω production we got $\sigma_\omega = 50 \pm 3^{+18}_{-16}\mu b$. For ϕ production we measured $\sigma_\phi = 0.09 \pm 0.007 \pm 0.04\mu b$. In contrast to the ρ^0 and ω, the polar angular distribution of the ϕ meson is isotropic within the errors, indicating a dominance of mesonic current. Compared to the model calculation of Sibirtsev [5], our measured ϕ/ω ration is about a factor of 3 larger.

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6.5 Vector Meson Production at TOF

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6.6 Phi Meson Production at ANKE

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As the first experiment with the new detection system for negatively charged ejectiles at ANKE [1, 2] ϕ-meson production has been investigated in pp collisions [3, 4, 5] by detecting the K^+K^- decay mode. First data have been taken at beam energies of 2.83 GeV and 2.7 GeV which correspond to excess energies of 76 MeV and 35 MeV. The measurements will be continued in the first weeks of 2004 at an excess energy of 18 MeV (T_p=2.65 GeV) (see arrows in the Figure of transparency no. 3) in order to provide the energy dependence in the near threshold region. The data will cover similar excess energies as the ω-data from SPES-III [6] and recent TOF [7] experiments. In addition to the understanding of the reaction $pp \rightarrow pp\phi$ near threshold [8], the data will thus provide information on the possible deviation from the cross-section ratio $R_{\mathrm{OZI}} = \sigma_\phi/\sigma_\omega = \tan^2\alpha_{\mathrm{v}} = 4.2\times10^{-3}$ given by the the Okubo-Zweig-Iizuka (OZI) rule with the ideal ϕ-ω mixing angle α_{v} [10]. Such a deviation of the ratio near threshold could be due to an intrinsic $s\bar{s}$ component in the nucleon, which would manifest itself in a ϕ production cross section significantly exceeding the limits given by the OZI rule.

Subsequent to the measurement $pp \rightarrow pp\phi$ at ϵ=18 MeV, ANKE will also collect data for the ϕ-meson production in pn collision at beam energy around T_p=2.75 GeV

[4, 9]. The $pn \to d\phi$ reaction can be identified by detecting the fast deuteron in coincidence with the K^+K^- pairs from the ϕ decay using the deuterium cluster-jet target. Apart from the unknown cross section [11, 14] this measurement could also be sensitive to the intrinsic strangeness. Following the arguments of Ref. [12], the expected cross section ratio $\sigma_{pp\to pp\phi}/\sigma_{pn\to d\phi}$ should be strongly enhanced according to the negatively polarized strangeness hypothesis. In contrast, no such enhancement is predicted by meson exchange models [13, 14].

The ϕ-meson production can also be studied in proton-nucleus reactions at ANKE by detecting only two particles, one K^- candidate in the negative and one K^+ candidate in the positive detection system [5, 15, 16]. For the background suppression the clean K^+ selection by using the particle range hodoscopes on the positive side is sufficient. Rate estimations show the possibility to collect for several targets up to 10000 K^+K^- correlations ($\approx$ 5000 ϕ-mesons) per nuclei in few weeks of beam time at ANKE. Several theoretical calculations [17, 18, 19] predict a significant change of ϕ properties - the pole mass and decay width - in nuclear matter. If the decay width increase by one order up to Γ_ϕ=45 MeV, then around 50% of the ϕ-mesons will decay inside of a Cu nuclei for an average momentum of p_ϕ=1.2 GeV/c at ANKE. Naively, one would expect to see a clear effect in the invariant mass distribution of the K^+K^- mesons. However, final-state interactions can strongly disturb the measured distributions and also Coulomb corrections and possible effects of the hadronic kaon potentials have to be taken into account. A recent calculation [20] uttered very skeptical about the visibility of ϕ in-medium properties through the K^+K^- invariant mass distribution. Nevertheless the authors mention that the reaction can give potentially further evidence for the modification of the masses of kaons and anti-kaons at finite baryon density.

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6.7 Omega Meson Production in pn Collisions at ANKE

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The comparison of the cross sections for meson production in proton-proton and proton-neutron collisions close to threshold, constrain theoretical models describing the production mechanisms. For η production the observed cross section ratio $R = \sigma_{\rm tot}(pn \to pn\eta)/\sigma_{\rm tot}(pp \to pp\eta) \approx 6.5$ is generally attributed to isovector dominance in model calculations based on meson exchange. It is therefore interesting to investigate whether a similar isospin dependence is found also for the ω, the next heavier isoscalar meson. Relatively few experiments were performed for the $pp \to pp\omega$ reaction, but in proton-neutron collisions no data whatsoever are available.

The $pn \to d\omega$ reaction was studied in the $pd \to p_{\rm sp}d\omega$ reaction at four proton beam momenta between 2.6 and 2.9 GeV/c at the ANKE spectrometer of COSY-Jülich. A deuterium cluster-jet target was used as an effective neutron target, detecting the low momentum recoil protons ($p_{\rm sp}$), which have momenta of about 80 MeV/c, in a silicon telescope placed close to the target. These recoil protons can be treated as "spectators" that influence the reaction only through their modification of the kinematics. By variation of angle and momentum of the spectator protons, a certain range in excess energy Q is selected experimentally. This range is used to extract results in pn collisions for the corresponding Q values. The deuterons emitted at angles below 8° with a momenta around 2 GeV/c were detected in the forward system of the ANKE spectrometer. Inclined Čerenkov counters in combination with two layers of scintillation counters enabled us to identify these deuterons despite a two orders of magnitude higher proton background. Their momenta were reconstructed using the information from two multi-wire proportional chambers.

The cross sections extracted for $pn \to d\omega$ at $Q \approx 26$ MeV and 60 MeV are significantly smaller than theoretical predictions. This suggests that the reaction mechanism for ω production differs from the one for the η, possibly implying a relatively larger contribution from isoscalar meson exchange. Measurements with higher precision in both Q and in cross section are scheduled already for August 2003. The results are expected to shed even further light on the basic production mechanisms.

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7 Hadrons in Nuclear Medium

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7.1 Hadrons in the Nuclear Medium

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7.2 Modification of kaon properties in nuclear matter

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We investigate the modification of kaons in isospin asymmetric nuclear matter. Using the leading s-wave couplings of the SU(3) chiral meson-baryon Lagrangian we solve the coupled channel kaon-nucleon scattering equation selfconsistently.

The in-medium kaon propagator is calculated for different densities and different proton/neutron ratios. The spectral function of the kaon is found to be broadened strongly, its mass shifted downward significantly.

However, comparing the effective in-medium mass of the kaon to the relevant charge chemical potential of neutron star matter, we find no indication of Kaon condensation.

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7.3 Strangeness Production on Nuclei with Hadronic Probes

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7.4 Investigation of K$^+$-meson production in pA collisions

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In a series of measurements with the ANKE spectrometer [1] at COSY-Jülich, the production of K^+-mesons in pA (A=C, Cu, Ag and Au) collisions in a wide range of beam energies, $T_p = 1.0 \ldots 2.3\,\text{GeV}$, has been investigated. Double differential cross sections $d^2\sigma/d\Omega dp$ for K^+ production in pC interactions have been evaluated. For the lowest incident proton energy it is the first measurement of a complete momentum spectrum at deep subthreshold energies [2].

The analysis of the target-mass dependence of the cross sections [3] does not allow to fix the underlying production mechanisms, though reveals other interesting aspects of the K^+ production on nuclei related to the final-state interactions effects. The strong suppression in the ratios of K^+ production on copper, silver and gold targets to that on carbon observed for $p_K <$ 200–250 MeV/c may be ascribed to a combination of Coulomb and nuclear repulsion in the K^+A system. Our data are consistent with a K^+A nuclear potential of $V_K^0 \approx 20\,\text{MeV}$ at low kaon momenta and normal nuclear density [4].

In addition to the direct production on a single target nucleon the K^+ mesons can also be produced in two-step processes with intermediate pion production, i.e a $pN_1 \rightarrow \pi X$ reaction, followed by $\pi N_2 \rightarrow K^+X$ on a second target nucleon. Depending on the beam energy, K^+-production may be due to both the direct and two-step reaction mechanisms. At low beam energies the two-step process is energetically favorable since the intrinsic nucleon motion can be utilized twice. A direct test of subthreshold K$^+$-production mechanisms comes as a measurement of K^+d and K^+p correlations.

First momentum spectra of protons and deuterons measured in coincidence with the K^+-mesons have been obtained at $T_p = 1.2\,\mathrm{GeV}$. These data supply direct evidence for the two-step reaction mechanism, with formation of intermediate pions, leading to kaon production. It has been shown, that the particular two-step mechanism $pN_1 \rightarrow d\pi$, $\pi N_2 \rightarrow K^+\Lambda$ contributes to about 30% of the total kaon yield at $T_p = 1.2$ GeV [5]. The data also indicate that a significant fraction of the K^+-mesons is produced on two-nucleon clusters, i.e. in the reaction $p(2N) \rightarrow (dK^+)\Lambda$. It is also shown that exploiting criteria of kinematics it is possible to study these mechanisms rather individually.

Another important aspect of K^+-production from nuclei is the equality or the difference in production on proton and neutron. Measurements of correlated K^+ mesons and protons allow one to clarify the situation comparing resulting spectra with corresponding simulations. Analysis of the experimental data measured at $T_p \approx 2\,\mathrm{GeV}$ suggests that the production on neutron exceeds that on proton, and the ratio of corresponding cross sections is close to 4.

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7.5 Strange Baryon Production at ANKE

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The production and properties of hyperons have been studied for more than 50 years, mostly in pion and kaon induced reactions. Hyperon production in pp collisions close to the threshold has been studied at SATURNE (Saclay, France) and COSY-Jülich. At COSY beam energies only six hyperons can be produced: $\Lambda(1116)$, $\Sigma(1192)$, $\Sigma(1385)$, $\Lambda(1405)$, $\Sigma(1480)$ and $\Lambda(1520)$. Reasonably complete information on $\Lambda(1116)$, $\Sigma(1192)$, $\Sigma(1385)$ and $\Lambda(1520)$ hyperon-production cross sections, found in the literature, is used for the normalisation of our data.

For the $\Lambda(1405)$, in spite of rather high statistics achieved (the total world statistics is several thousand events), there are still open questions concerning the nature of this resonance: is it a singlet qqq state in the frame of SU(3) or a quark-gluon *(uds-q)* hybrid, or a KN bound state? Thus more detailed studies of different decay modes of the $\Lambda(1405)$ are needed for a better understanding of its nature.

The $\Sigma(1480)$ hyperon is not well established yet. In the 2002 Review of Particle Physics it is described as a 'bump' with unknown quantum numbers. The branching ratios for possible decay modes ($N\overline{K}, \Lambda\pi, \Sigma\pi$) are known with errors between 60 and 70 %. The total world statistics for this 'bump' is less than two hundred events.

Both $\Lambda(1405)$ and $\Sigma(1480)$ were produced mainly from decays of heavier hyperons in kaon and pion induced reactions. At COSY they are produced directly in $pp{\rightarrow}K^+pY^*$ reactions. It is essential that the ANKE spectrometer permits the simultaneous observation of different decay modes: $Y^*{\rightarrow}\pi^+\Sigma^-$, $Y^*{\rightarrow}\pi^-\Sigma^+$ and

$Y^* \to K^- p$. To realize this project it is necessary to analyse triple coincidences: positively and negatively charged particles detected by the three different parts of the ANKE detector system (side, forward and negative).

The first measurement of pp interactions using a cluster-jet hydrogen target, carried out in spring 2002, demonstrated the feasibility of these studies at ANKE.

In the missing mass spectrum in the reaction $pp \to K^+ p M_X$, resulting from detection of the 2-fold K^+p coincidences at proton beam energy $T_p = 2.83\,\mathrm{GeV}$, different hyperons ($\Lambda(1116)$, $\Sigma(1192)$, $\Sigma^*(1385)$, $\Lambda^*(1405)$, $\Sigma^*(1480)$) and hyperons with additional pions ($\Lambda\pi$, $\Sigma\pi$, $\Sigma\pi\pi$) were identified.

The 3-fold $K^+ p \pi^+$ coincidences were selected to study heavier hyperons Y^* ($\Sigma^*(1385)$, $\Lambda^*(1405)$, $\Sigma^*(1480)$). A missing mass spectrum in the reaction $pp \to K^+ p \pi^+ M_X$ consists of a flat plateau with a peak at approximately 1195 MeV. The peak corresponds to the decay $Y^* \to \pi^+ \Sigma^-$. If only events with $M_X = (1195 \pm 20)\,\mathrm{MeV}$ are selected, then the m_x spectrum in the reaction $pp \to K^+ p$ ($m_x = \pi^+ + M_X$) shows two peaks with a width of 45 MeV each. One of them corresponds to the contribution of $\Sigma(1385)$ and $\Lambda(1405)$ hyperons. The second peak can be ascribed to the production of the $\Sigma(1480)$. In order to prove this a similar analysis of 3-fold $K^+ p \pi^-$ coincidences is in progress.

7.6 Hadron Induced two Pion Production in Nuclei

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Topic of this talk is the search for medium modifications of the sigma meson. The sigma is identified as the $f_0(600)$ by the particle data group [1] with uncertain mass between 400 and 1200 MeV and large width of 600 to 1000 MeV. The interpretation of the sigma is controversial, it has been described as a pion-pion

interaction resonance in the I=L=0 channel, i.e. a $q\bar{q}q\bar{q}$ state, or as an intrinsic $q\bar{q}$ meson [2]. In the latter interpretation, it has been put forward as the chiral partner of the pion, which should be severely affected in mass and width in the nuclear medium due to the partial restoration of chiral symmetry. The interpretation as a pion-pion-resonance also leads to property changes as a consequence of medium-modifications of the pion-pion-interaction.

The sigma channel can be accessed by observing I=L=0 pion pairs. First information came from the CHAOS experiment at TRIUMF, which measured pion-pion invariant mass spectra in the pion-induced pion production reactions $(\pi^+, \pi^+\pi^-)$ and $(\pi^+, \pi^+\pi^+)$ for various nuclei (D, ^{12}C, ^{40}Ca, ^{208}Pb). While the I=2 $\pi^+\pi^+$ channel was not affected by the choice of target, a clear A-dependent accumulation of strength at low invariant masses was seen for the $\pi^+\pi^-$ channel [3]. A similar effect was observed in the $(\pi^-, \pi^0\pi^0)$ reaction by the Crystal Ball collaboration at BNL [4,5]. A calculation by the Valencia group, including medium effects as modification of the pion-pion-interaction, failed to describe the size of the enhancement at low invariant masses [4,6].

This is contrasted by the situation for the $(\gamma, \pi^0\pi^0)$ reaction in nuclei, which was investigated by the TAPS/A2 collaboration at MAMI. Also here, modifications of the pion-pion invariant mass spectra were observed, but the changes are in quite good agreement with the Valencia group calculations [7,8].

This different behavior of the pion- and photon-induced reactions is not understood. The Valencia group suggests that the failure of the description for the pion-induced reaction might be due to accidental strong cancellations of parts of the reaction amplitude in the case of the pion-induced reaction. This explanation can be checked by measuring the behavior of a third production mechanism, the proton-induced two pion production. Investigation of this reaction in nuclei is planned with the TOF detector at COSY and the WASA detector at TSL.

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7.7 Double Pion Photoproduction from Nuclei

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The interest in modifications of hadron properties in the nuclear medium is motivated by the origin of hadron masses in the context of spontaneous chiral symmetry breaking and their modification in a hadronic environment due to chiral dynamics and partial restoration of chiral symmetry [1, 2].

The photoabsorption cross section on the proton [3] for E_γ <800 MeV can be explained by the sum of the meson production channels: single π^+ [4, 5], single π° [6], $\pi^+\pi^-$ [7, 8], $\pi^+\pi^\circ$ [9], $\pi^\circ\pi^\circ$ [10, 11], and η [12, 13]. In the second resonance region, the dominant contribution is the $D_{13}(1520)$ resonance with the strongest coupling to the incident photon. $\pi\pi$ production reveals sequential resonance decay via an intermediate Δ state [10]. In $\pi^+\pi^\circ$, a decay branch of 20% $N^\star \to N\rho$ is deduced [9]. The N^* contribution to double pion photoproduction by itself is not large. The structure stems from an interference with other terms [14, 15].

The comparative study of the nuclear photoabsorption [16] from nuclei (A>6) with the elementary photoabsorption show that the cross sections follow a universal

behavior $\sigma \sim 1/A$; the Δ resonance is broadened and slightly shifted; the higher resonance regions appear depleted. The depletion of nuclear cross sections in the second resonance region is evidence for modifications of hadron properties in the nuclear medium. 'Trivial' medium effects on baryon resonance parameters like Fermi motion, collision broadening, quenching, and Pauli blocking, do not explain the effect. An in-medium broadening of the $D_{13}(1520)$ resonance could cause of the depletion on account of the coupling to the $N\rho$ final state [20]. The ρ-meson itself is expected to be appreciably broadened in the nuclear medium [21]. In [22], the disappearance of the second resonance structure is related to a cooperative effect of the interference in double pion production processes, Fermi motion, collision broadening of the Δ and N^* resonances, and pion distortion in the nuclear medium. Systematic studies of quasifree meson production have not yet provided a hint for a depletion of the resonance yield. Single π° [17] and η [18, 19] photoproduction cross section from nuclei show a reduction and change of resonance shapes that can be explained by trivial effects like absorption, Fermi smearing and Pauli blocking, and collision broadening. The resonances of the second resonance region seem to maintain their structure in the nuclear medium. In a more detailed study, invariant $\pi\pi$ mass distributions indicate a modification of the pion-pion interaction in the scalar-isoscalar state [23, 24], similar to the dropping mass scenario expected from partial chiral symmetry restoration [1].

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7.8 K^+ and K^- Mesons in Heavy Ion Collisions at SIS Energies

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7.9 Strange Baryons in Matter

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7.10 Baryonic resonances in NN and N–nucleus collisions

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Within an effective Lagrangian model, we present calculations for cross sections of kaon [1,2] and dilepton productions [3] in nucleon-nucleon (NN) collisions for beam energies below 10 GeV. The initial interaction between the two nucleons is modeled by the exchange of π, ρ, ω and σ mesons. The particle production in the final channel proceeds via excitation, propagation and decay into relevant channels of the nucleon resonances which have large branching ratio for decays into those channels. In case of K^+ production, the relevant resonances are $N^*(1650)$, $N^*(1710)$, and $N^*(1720)$ while for dileptons they are $\Delta(1232)$ and $N^*(1520)$. The parameters of the model at the NN-meson vertices are determined by fitting the NN elastic scattering T matrix with effective Lagrangians based on the exchange of these four mesons, while those at the resonance vertices are calculated from the known decay widths of the resonances. We find that the associated $K^+\Lambda$ and $\Sigma^0 K^+$ productions are dominated by the contributions coming from $N^*(1650)$ resonance

for near threshold beam energies while $N^*(1710)$ dominates the cross sections at higher beam energies. One pion exchange contributions are most important in the entire beam energy region. The dilepton production is dominated by the $\Delta(1232)$ contributions for beam energies in 1-5 GeV range. The effective Lagrangian model calculations are able to explain the data of the DLS Collaboration on the dilepton production in proton-proton collisions for beam energies below 1.3 GeV. However, for incident energies higher than this the inclusion of contributions from other dilepton sources such as Dalitz decay of π^0 and η mesons and direct decay of ρ^0 and ω mesons is necessary to describe the data.

We also calculate the exclusive K^+ meson production in a proton-nucleus collision leading to two body final states within a fully covariant two-nucleon model based on the same effective Lagrangian and the corresponding coupling constants [4]. The calculated cross sections show strong sensitivity to the medium effects on pion propagator and to the final hypernuclear state excited in the reaction.

This work has been done in collaboration with H. Lenske and U. Mosel and is supported by the Forschungszentrum Jülich.

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8 Accelerator

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8.1 COSY Status

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8.2 Polarization Development

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Polarized proton beams at COSY are routinely delivered to internal and external experiments. The polarized beams from the ion source are pre-accelerated in the cyclotron JULIC and injected and accelerated in COSY without significant loss of polarization. Imperfection resonances are increased in strength by means of vertical orbit distortions, leading to a complete polarization reversal (spin flip). Intrinsic resonances are overcome by means of a fast ramping air core quadrupole magnet inducing a rapid change in tune and therefore preservation of the polarization (tune jump).

The polarization during acceleration is observed utilizing parts of the former EDDA detector system as polarimeter. Only the fast online polarization measurements during the COSY acceleration cycle made possible by the EDDA setup allows an efficient correction of the upto 13 first order depolarizing resonances encountered.

Polarized deuterons were accelerated for the first time early in 2003. Because of the lack of depolarizing resonances in the COSY energy range, preservation of the polarization is less involved for deuterons compared to protons. However, a polarization

measurement technique for vector and tensor polarization has to be developed. It is intended to use for this task parts of the former setup of EDDA. So far only a relative measurement of the vector polarization was possible. However, this was already sufficient to carry out a first investigation of the polarization reversal of a polarized deuteron beam by crossing of an RF dipole induced depolarizing resonance [1].

Polarized proton beams with intensities above 10^{10} stored protons with a degree of polarization of upto 0.80 are now routinely delivered to internal experiments. For external experiments polarized protons can be slowly extracted from COSY via stochastic extraction without loss of polarization by keeping the extraction momentum far enough away from depolarizing resonances and careful adjustment of the betatron tunes during the extraction process. As an example, 10^8 protons/second at 1.4 GeV/c with a polarization of 0.80 were delivered to the TOF experiment recently.

A more detailed study of higher order depolarizing resonances in the vicinity of the strongest first order intrinsic resonance (8-Qy), located close to a beam momentum of 2.1 GeV/c will be conducted to minimize the remaining small polarization losses. Furthermore the investigation of spin flipping of polarized protons and deuterons at fixed energies within an international collaboration will be continued.

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8.3 Intensity Upgrade @ COSY

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The aim of the Intensity Upgrade @ COSY is to reliably increase the intensity of the polarized proton beam in COSY typically by a factor of three compared to

what can be delivered to experiments at present. Therefore, the beam transmission in the whole accelerator chain is investigated to search for potential improvements. The performance of the system not only depends on the transmission but also on the beam quality delivered by the various subsystems. Hence, the measurement of key beam properties plays a major role in the intensity upgrade program.

Most promising tasks of the intensity upgrade program are improvements of the source performance and transmission in the source beamline, the characterization of beam delivered by the cyclotron, securing the long term availability of cyclotron RF system, fine tuning of the betatron amplitudes in the injection beamline, further investigation of the potential of beam debunching for the COSY injection, the maximization of the COSY acceptance, capture and acceleration efficiency in COSY and careful revision and optimization of the COSY magnet ramps.

In the first beam time an optimized injection setting with unpolarized beam has been developed. The intensity of the injected beam could be increased by a factor of about two, as presented in this talk. Detailed investigation of all system parameters and beam properties will allow an adopted set-up of COSY with increased performance.

The improved capabilities will enable us to further exploit the unique experimental opportunities of the COSY facility.

9 Baryon Resonances

Convenors: S. Krewald and H.-P. Morsch

9.1 Baryon Resonances

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Baryon resonances show the dynamical structure of baryons in a direct way and are therefore uniquely suited to investigate the properties of QCD in the non-perturbative regime. Presently, there are significant theoretical efforts to investigate these resonances in different models and approximation schemes of QCD. On the other hand, there are large experimental programs with electromagnetic and hadronic probes to study the detailed properties of the resonances.

Several aspects of N* physics were discussed in the afternoon session; therefore the present discussion is restricted mainly to the lowest N* resonances. A detailed study of the Roper resonance, $P_{11}(1440)$, has shown, that this resonances is excited differently in different reactions: in α-p scattering [1] a N* resonance is observed at a mass of 1400 MeV with a width of about 200 MeV, whereas π-N [2] shows a large resonance with a width of 300-360 MeV. These observations have led to an interpretation of the Roper resonance in terms of two structures [3]. Excitation by photons, in which the first resonance is not observed, supports this interpretation.

Formerly, N* resonances have been investigated in high energy (p,p'), (π,π') [4] and (e,e') reactions. In proton and pion scattering N* resonances were observed at masses of the $\Delta(1232)$, 1400 MeV, 1510 MeV, 1690 MeV and 2190 MeV. The last three resonances correspond to $D_{13}(1520)$, $F_{15}(1680)$ and $G_{17}(2190)$. With electrons the same resonances were observed, except for the resonance at 1400 MeV. The cross section of this resonance shows a strong fall-off with momentum transfer, characteristic of L=0 excitation. Therefore, this resonance can be identified as

$P_{11}(1400)$. Remarkably, this structure corresponds in energy and width exactly to the P_{11} resonance observed strongly in α-p scattering [1].

There are also old exclusive (p,p'x) data available [5], which give information on the decay properties of the observed resonances. In the invariant $\pi^+\pi^-$ mass spectrum a prominant peak is observed at the mass of the $P_{11}(1400)$, which indicates strong 2π-N decay of this resonance.

Experiments are in preparation at COSY, in which N* resonances will be studied in p-α interactions using a proton beam up to 2.5 GeV and a thin ^4He target. The recoil ^4He-particles will be registered in Silicon microstrip ΔE-E detector telescopes, whereas the N* decay products will be detected in the large acceptance detector TOF. We expect, that in these experiments N* production will be strongly increased with respect to the Saturne experiment and possible up to much larger mass, allowing for more detailed investigations.

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9.2 Introduction to the Baryon sesssion

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Presently, we are living in an exciting period in which experiments present increasingly strong evidence for a pentaquark[1] predicted a long time ago by Diakonov,

Petrov and Polyakov who assumed the $N(1710, \frac{1}{2}^+)$ to be a member of an antidecuplet. Today's session focusses on another non-q^3 candidate, the so-called Roper resonance, $N(1440, \frac{1}{2}^+)$. Problems of traditional quark models to reproduce the mass of this resonance have triggered the idea that the Roper might have an exotic structure [2, 3]. On the other hand, instanton motivated effective quark interactions or color singlet interactions have been used to reduce the mass of the Roper assuming a pure three-valence quark structure[4, 5]. Several Lattice groups have reported results concerning excited nucleons and found produce Roper masses well above the experimental value, see e.g. [6]. Recent calculations based on the overlap realisation of a lattice fermion action possessing an exact chiral symmetry pushed the pion masses down to 180 MeV and have obtained a considerable lowering of the lattice Roper mass which now degenerates with the lattice $N(1535)$,however [7].

The Juelich theory group[8] treats the pion-nucleon reaction by coupling the reaction channels πN, ηN, ρN, σN, and $\pi\Delta$ within a meson-exchange model. This model incorporates the most relevant reaction channels for one- and two-pion decays of the resonances. The model provides a theory for the physical background due to meson-baryon interactions. The background may show some structure because the exchange of mesons in the t-channels can act as a long-range attraction between meson and baryon and thus lead to a somewhat localized enhancement of strength. In order to reproduce resonances with a relatively narrow width, such as the Δ_{33}, one has to introduce pole diagrams, however, which are interpreted as bare triple quark states. It was found that all pion-nucleon resonances below 2 GeV require pole diagrams within this formalism, with one exception: the $N^*(1440)$.

On the experimental side, there has been considerable progress. Two-pion production in proton-proton reactions measured at CELSIUS appear to demand a strong two-pion decay of the Roper resonance[9, 10], as suggested by the Julich model. One has to note, however, that the theoretical analysis of the data deserves further scrutiny.

The CRYSTAL BALL collaboration has presented data for the reaction $\pi^- p \to \pi^0\pi^0 n$ [11]. The theoretical model for this reaction presented by S. Schneider ap-

pears to be compatible with the Crystal ball data which would be further evidence for a significant role of the Roper.

The alpha particle has been shown to excite the Roper in inclusive reactions[12], exclusive reactions hopefully will be presented in the near future.

At a first glance, photon-induced reactions appear not to be a suitable probe to investigate the Roper resonance because the photoproduction of two neutral pions is dominated by the D13(1520)[13]. This situation may change radically in the near future because both polarized photons and polarized targets have become available. As is discussed by R.Beck, these new experimental achievements will allow to filter out the Roper contribution from the photo-induced cross sections. Moreover, at Jlab, the CLAS collaboration has started to provide electron-induced cross sections which allow to map out the momentum dependence of the various reactions. L.Tiator presents first analyses of the data. Some quark models produce transition amplitudes for the Roper which vanish at some momentum transfer well below 1 GeV/c[14]. It will be very exciting to see whether such a node in the transition amplitude is compatible with the data.

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9.3 Baryon excitations in a relativistic quark model

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On the basis of the three-particle Bethe-Salpeter equation we formulated a relativistic quark model for baryons. Because neither the full quark propagator nor the interaction vertices are reliably known from QCD, we make two basic phenomenological approximations: Quark propagators have the free form with an effective constituent mass and the interactions are assumed to be given by unretarded potentials, both assumptions are motivated by the apparent success of non-relativistic quark models. The interaction potentials include a string-like linearly rising three-body confinement potential with a suitable spin-dependence and a spin-flavor dependent qq-interaction motivated by instanton effects, taken into account by the perturbative construction of an effective three-body kernel. This framework was applied to calculate the complete mass spectrum of light-flavored baryons up to 3 GeV. Constituent quark masses and confinement parameters were fixed to the Δ-Regge trajectory and those of the instanton-induced interaction (acting on flavor-antisymmetric quark pairs only) to the ground-state hyperfine splittings, the rest of the spectrum thus being a genuine prediction. We can describe all the major

features in the experimantal baryon spectra, in particular the conspicuous low position of the Roper-resonance, and the approximate parity doublets apparent in the N- and Λ spectra [1]. Form factors and decay properties of baryon resonances were calculated in the present covariant framework in the Mandelstam formalism. All model parameters being fixed from the baryon mass spectrum the calculation of electromagnetic properties constitutes a genuine prediction: We find a good description of static electroweak properties, the magnetic and axial nucleon form factors and the magnetic $N-\Delta$-transition form factor up to moderate (3-4 GeV^2) momentum transfers [1]. A novel approach to calculate magnetic moments directly as an expectation value of a local oparator with Salpeter amplitudes is presented. Results on other transition form factors and helicity amplitudes are presented. Strong two-body decay widths of baryon resonances can also be obtained parameterfree by calculating in lowest order the contribution of single quark-loops. First results on the decay widths of some low-lying baryon resonances are discussed.

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9.4 Crystal Barrel Results

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The study of nucleon resonances provides important information on many open questions in baryon spectroscopy. The key to any progress is the identification of the effective degrees of freedom leading to a qualitative understanding of strong QCD. The problem of *missing resonances* predicted by quark models is reviewed

on the basis of experimental results of the CB-ELSA experiment at the e^- accelerator ELSA in Bonn. Differential and total cross sections of $\gamma\, \mathrm{p} \;\rightarrow\; \mathrm{p}\, \pi^0$ and $\gamma\, \mathrm{p} \;\rightarrow\; \mathrm{p}\, \eta$ have been determined for incident photon energies up to $E_\gamma = 3$ GeV. At low energies, results of experiments such as GRAAL and CLAS are well reproduced. New data points have been added to those results for forward angles of the meson and at energies above 2 GeV. In the differential cross sections of both, π^0 and η photoproduction, a transition from dominant resonance production to a strong peaking in the forward direction can be observed around $E_\gamma = 2$ GeV.

Furthermore, resonance production and even cascades of the type $\mathrm{N}^{**}(\Delta^{**}) \rightarrow \mathrm{N}^{*}(\Delta^{*}) \rightarrow \mathrm{p}\pi^0\pi^0(\mathrm{p}\pi^0\eta)$ are observed. Indications for at least one Δ resonance around 1900 MeV are seen. The latter is particularly interesting if it had negative parity because a confirmation of this state would be in contradiction with constituent quark models [1, 2].

The Crystal Barrel detector is the ideal instrument to study various multi-photon final states over the full dynamical range due to its almost 4π coverage of the solid angle and its large energy resolution. It allows to identify highly-excited baryon states by observing cascades of high-mass states to the ground state via the emission of single pion and eta mesons. The latter could be observed in the 2001 CB-ELSA data for the reaction $\gamma\, \mathrm{p} \;\rightarrow\; \mathrm{p}\, \pi^0\, \eta$, for instance. It could be shown in partial wave analyses that linearly polarised photons are very important in order to avoid ambiguities in determining the corresponding quantum numbers. In 2002/2003, polarised data have been taken off the proton as well as off the neutron with the Crystal Barrel detector and TAPS in the forward direction as a fast trigger forming an ideal photon detector of high granularity (CB-TAPS).

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9.5 Two-Pion Production in Proton-Proton Collisions

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In nucleon-nucleon induced two-pion production the correlated two-pion exchange between the interacting nucleons is lifted onto the mass shell. This reaction gives rise to a number of subsystems, where the different aspects of this process can be studied. Among these subsystems the $NN\pi$ system is special, since it facilitates the search for narrow, in particular NN-decoupled dibaryon resonances. First exclusive measurements at CELSIUS have provided [1] new and significant upper limits in the range of a few nb for the low-mass region $m_{dibaryon} < 2087$ MeV/c^2. For a review on the present status of dibaryon searches see [2]

In the $\pi\pi$ subsystem the dynamics in σ and ρ channels is of topical interest. In combination with the $N\pi$ and $N\pi\pi$ subsystems it gives access to the investigation of nucleon excitations and their decay properties. Particular emphasis is placed here on the investigation of the Roper resonance, the second excited state of the nucleon in the non-strange sector, since its nature and properties are still very poorly known.

Our first exclusive measurements of the $pp \to pp\pi^+\pi^-$ reaction near threshold [3, 4, 5] reveal this reaction to be dominated by σ-exchange between the colliding nucleons followed by the Roper excitation in one of the nucleons with subsequent decay into $N\sigma$ or $\Delta\pi$ channels. From the observed interference of both decay routes into the final $N(\pi\pi)_{I=l=0}$ state their relative amplitudes and branchings have been determined [2, 5] in the low-energy tail of the Roper excitation. Though we observe this low-energy region to be strongly dominated by the $N\sigma$ channel, we also see a small but rapidly growing influence of the $\Delta\pi$ channel as the energy is increased. Due to its k^2 dependence the amplitude of the latter is even likely to take over at the position of the Roper resonance pole [2, 5].

These findings are basically in agreement with theoretical predictions of the Valencia group [6, 7]. However, there are also significant deviations in particular with respect to new measurements of this reaction in the threshold region with the polarized proton beam at COSY-TOF [8]. There the preliminary data analysis yields partly non-zero analyzing powers, which point to perceptible admixtures of $l \neq 0$ partial waves in $pp \to pp\pi^+\pi^-$, in particular in the $\pi\pi$ system.

With the new WASA 4π detector at CELSIUS a program has been started to measure the two-pion production exclusively in all channels over a wide energy range. First data for the $pp\pi^0\pi^0$ channel find the influence of the $N^* \to \Delta\pi \to N\pi\pi$ route to be considerably weaker than expected from the $pp\pi^+\pi^-$ channel assuming isospin invariance, which points to possible ρ channel admixtures in the latter. At incident energies above 1 GeV we observe drastic changes in the spectra. In $M_{p\pi}$ spectra we observe a clear peak which may be associated with Δ excitation, whereas the $M_{\pi\pi}$ spectra essentially fall back to phase space.

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9.6 What can we learn about Baryon Resonances from $\pi N \to \pi\pi N$?

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Most of our knowledge of baryon resonances comes from the analysis of πN scattering. In order to obtain more detailed information on the decay properties of resonances, we directly study the decay to the inelastic channels in the reaction $\pi N \to \pi\pi N$. We investigate the reaction in the framework of a resonance exchange model. The intermediate resonances are the ρ and σ mesons and the baryonic resonances $P_{33}(1232)$, $P_{11}(1440)$, $D_{13}(1520)$, and $S_{11}(1535)$. It has been checked that the corresponding subgraphs of the $\pi N \to \pi\pi N$ model are able to describe $\pi\pi$ scattering and πN scattering reasonably well.

We observe a substantial contribution from the Roper Resonance in the reaction channels $\pi^- p \to \pi^+\pi^- n$ and $\pi^- p \to \pi^0\pi^0 n$. In the energy range above $T_\pi \approx 270$ MeV we clearly need the contribution of the Roper Resonance, but in the threshold region it leads to an overestimation of the cross section data. The problem can be mended by switching off the Roper $\to \sigma N$ decay and readjusting the Roper $\to \pi\Delta$ decay constant. This leads to a stronger rise of the Roper contribution with energy and even allows for an almost perfect description of the differential cross sections for $\pi^- p \to \pi^+\pi^- n$ that are available up to $T_\pi = 305$ MeV. But switching off the Roper $\to \sigma N$ decay would spoil the description of the πN inelasticities in the P_{11} partial wave. There, one needs the σN decay in order to reproduce the early onset of the inelasticities.

These results certainly need further investigation. In particular, it will be necessary to improve the model by including a 4π and a $3\pi NN$ contact term, which are needed to respect chiral symmetry.

9.7 Two π Invariant Mass Spectra from $\alpha p \to \alpha' p X$

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9.8 N^* Experiments with Polarized Photons

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9.9 Electroproduction of Nucleon Resonances with MAID

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MAID is a unitary isobar model for pion photo- and electroproduction on the nucleon, accessible in the internet [1]. It can be applied for energies from pion threshold up to $W = 2$ GeV covering most of the resonance region. From real photons at $Q^2 = 0$ up to photon virtualities of $Q^2 = 5$ GeV^2 it can be used for online calculations of multipoles, amplitudes, cross sections, polarization observables and sum rules. The model is based on a nonresonant background dominated by Born and vector meson exchange terms and a resonance part described by Breit-Wigner functions. Both parts are individually unitarized and fulfill the Watson theorem below the two-pion threshold. While in MAID2000 only the 8 most prominent nucleon resonances were included, we have recently extended the resonance sector and now all four-star resonances below $W = 2$ GeV are included.

Using the world data from the GW/SAID database for pion photo- and electroproduction and recent electroproduction data from Bonn, Bates and JLab we have

performed energy dependent single Q^2 fits and an energy- and Q^2 dependent "superglobal fit" of nucleon resonance excitation.

Our first and preliminary analysis shows quite stable results for the Δ excitation as well as for the transverse amplitudes of the $D_{13}(1520)$ and the $S_{11}(1535)$. For most other resonances the data show large fluctuation that are much bigger than the statistical uncertainties. Such model-dependent results reflect the poor situation in the data base in some kinematical regions and the lack of polarization observables that are essential, e.g. for the analysis of the Roper resonance.

A comparison of our analysis with the results of the hypercentral constituent quark model of the Genova group (HCQM) [2] shows large differences between the quark model and the experimental analysis. In the case of the magnetic form factor $G_M^*(Q^2)$ of the Δ excitation this has long been known from many quark model calculations. But most dramatically this now appears for the longitudinal Δ excitation, $G_C^*(Q^2) \sim S_{1/2}(Q^2)$, where the HCQM gives an almost zero result but the experimental numbers are quite large with relatively small uncertainties.

In a recently developed dynamical model (DMT) [3] for pion-nucleon scattering and pion electroproduction we have shown that this puzzle can be solved in terms of the pion cloud contribution. In a dynamical approach the pion-loop integrals give additional contributions at the resonance position which are neglected in the usually applied K-matrix approach. This pionic contribution can fully explain the longitudinal Δ excitation and also solves the old puzzle of the missing strength in the magnetic Δ excitation.

In conclusion, we find that microscopic calculations without pionic degrees of freedom (e.g. constituent quark models) of nucleon resonance excitation cannot be directly compared with experimental numbers obtained in a K-matrix approach, but have to be compared with a dynamical model that treats the pionic contribution explicitly.

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10 Scalar Mesons

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10.1 Investigation of light scalar mesons $a_0/f_0(980)$ at COSY

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One of the primary goals of hadronic physics is the understanding of the internal structure of mesons and baryons, their production and decays, in terms of quarks and gluons. The non-perturbative character of the underlying theory — Quantum Chromo Dynamics (QCD) — hinders straight forward calculations. QCD can be treated explicitly in the low momentum-transfer regime using lattice techniques[1], which are, however, not yet in the position to make quantitative statements about the light scalars. Alternatively, QCD inspired models, which use effective degrees of freedom, are to be used. The constituent quark model is one of the most successful in this respect (see e.g. [2]). This approach naturally treats the lightest scalar resonances $a_0/f_0(980)$ as conventional $q\bar{q}$ states. However, they have also been identified with $K\bar{K}$ molecules [3] or compact qq-$\bar{q}\bar{q}$ states [4]. It has even been suggested that at masses below 1.0 GeV a complete nonet of 4-quark states might exist [5].

The existing data base is insufficient to conclude on the structure of the light scalar mesons and additional observables are urgently called for. In this context the charge-symmetry breaking (CSB) a_0-f_0 mixing plays an exceptional role since it is sensitive to the overlap of the two wave functions. It should be stressed that, although predicted to be large long ago [6], this mixing has not unambiguously been identified yet in corresponding experiments.

At COSY an experimental program has been started which aims at exclusive data on a_0/f_0 production close to the $K\bar{K}$ threshold from pp, pn, pd and dd interac-

tions — i.e. different isospin combinations in the initial state [7, 8, 9, 10, 11, 12]. Data taken at the COSY-11 [7] and MOMO [8] facilities for $pp \rightarrow ppK^+K^-$ and $pd \rightarrow {}^3HeK^+K^-$ reactions are not conclusive about the contribution from the a_0/f_0 resonances. In the first experiment at the ANKE spectrometer the reaction $pp{\rightarrow}dK^+\bar{K}^0$ has been measured exclusively at excess energies $Q = 46$ and 106 MeV above the $K\bar{K}$ threshold. The data for the lower energy have already been analyzed and show that most of the $K\bar{K}$ pairs are produced in a relative s-wave which has been interpreted in terms of dominant a_0^+ production, $\sigma(pp{\rightarrow}da_0^+{\rightarrow}dK^+\bar{K}^0) = 83\% \cdot \sigma(pp{\rightarrow}dK^+\bar{K}^0) = 32$ nb [13]. Based on these data (and on model calculations for the different initial isospin configurations [14]) it is concluded that the production cross section for the light scalar resonances in hadronic interactions is sufficiently large to permit systematic studies at COSY.

If in the future a neutral-particle detector (like WASA) will be available at COSY, the a_0/f_0 can also be detected via their decays $a_0^{\pm} \rightarrow \pi^{\pm}\eta$, $a_0^0 \rightarrow \pi^0\eta$ and $f_0 \rightarrow \pi^0\pi^0$, $f_0 \rightarrow \pi^+\pi^-$. The strange decay channel $a_0/f_0 \rightarrow K_SK_S$ should be measured in parallel and the results can be compared with those from ANKE for the charged kaons. Since it is possible to manipulate the isospin of purely hadronic reactions it is possible to identify observables that vanish in the absence of charge-symmetry breaking (CSB) [15, 16]. Most promising for the extraction of CSB effects seems to be the reaction $dd \rightarrow \alpha(\pi^0\eta)$. Since the initial deuterons and the α particle in the final state have isospin I=0 ("isospin filter"), any observation of $\pi^0\eta$ production in this particular channel is a direct indication of CSB and can give information about the a_0-f_0 mixing [17].

The idea behind the proposed experiments is the same as behind recent measurements of CSB effects in the reactions $np \rightarrow d\pi^0$ [18] and $dd \rightarrow \alpha\pi^0$ [19] which found broad interest also outside the "hadron community". However, the interpretation of the signal in the case of the scalar mesons is largely simplified compared to the pion case. Since the a_0 and the f_0 are rather narrow overlapping resonances, the a_0-f_0 mixing in the final state is enhanced by more than an order of magnitude compared to CSB in the production operator (i.e. "direct" CSB violating $dd \rightarrow \alpha a_0$

production) and should give the dominant contribution to the CSB effect via the reaction chain $dd \to \alpha f_0(I{=}0) \to \alpha a_0^0(I{=}1) \to \alpha(\pi^0\eta)$ [17].

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10.2 Experiments on Light Scalar Mesons

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Lattice gauge calculations predict the existence of glueballs[1]. In particular a scalar glueball is firmly expected at a mass of about 1730 MeV. This prediction has led to an intense study of scalar isoscalar interactions and to the discovery of many new meson resonances[2]. The number of scalar states observed seems to exceed the number of states which can be accommodated in the quark model even when two states, the $a_0(980)$ and $f_0(980)$, are interpreted as $|\mathrm{K\bar{K}}>$ bound states and are removed from the list. However, none of these states has a decay pattern which is

consistent with that of a pure glueball. A reasonable interpretation of the number of states and of their decay pattern is found only when mixing of scalar $q\bar{q}$ states with the scalar glueball is taken into account[3].

However, alternatetive interpretations are conceivable or even more likely. The pole positions of scalar mesons are strongly influenced by their couplings to the final–state mesons. If the 'true' meson masses can be identified with the K–matrix poles, then a very different scalar meson mass spectrum evolves which is easily mapped on the scalar mass spectrum calculated from a relativistic Lipman-Schwinger equation using instanton–induced forces as interaction kernel[4]. A broad 'background' in the data can then possibly be identified with a scalar glueball[5].

A third interpretation questions the $q\bar{q}$ nature of the $f_0(1370)$. This state is a cornerstone in all $q\bar{q}$-glueball mixing scenarios. If it is interpreted as $\rho\rho$ system interacting by pion exchange, then the remaining scalar states are easily fit into a nonet classification. If this interpretation should be correct there would be no room for resonant scalar gluon-gluon interactions, no room for the scalar glueball[6].

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10.3 Production of the $f_0(980)$ in peripheral pion-proton reactions

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To describe pion production in the peripheral pion proton reaction $\pi^- p \to \pi^0 \pi^0 n$ it is sufficient to consider the final state interaction of the outgoing mesons since due to the interaction kinematics the nucleon will only interact once with the mesons. This is why we can use the Jülich meson exchange model for meson-meson interaction to describe the final state interaction. The production itself is described by the emission of a π / a_1 from the nucleon vertex. Because of the high momentum of these particles we use Regge amplitudes as parametrised in [1] to describe the initial production. We do not account for interference of the two production mechanisms since they mainly occur in different helicity amplitudes as the a_1 mainly conserves the helicity of the nucleon and the π mainly flips the helicity of the nucleon. To reproduce the t-dependence of the integrated experimental cross section we need to attach exponential form factors to the nucleon vertex as it is done in the experimental analysis. We fix the parameters from the $\frac{d\sigma}{dt}$ data given in [2]. Comparing our predicted production rates to the BNL data [2] for $\pi^- p \to \pi^0 \pi^0 n$ in various t-bins we find good agreement. We are further able to reproduce the kaon production data from [3]. We see how the structure at $m_{\pi\pi} = 1$ GeV is formed by an interplay of a high lying state stemming from the confinement spectrum with a $K\bar{K}$ molecule formed due to the attractive t-channel meson exchanges. Sadly the data is inconclusive when it comes to the properties of this state as we will discuss now. First let us elaborate in which way results depend on the momentum of the initial pion beam. First of all we expect an overall scaling of the data by a

factor $\frac{1}{q_{\mathrm{beam}}^2 s_{\mathrm{tot}}}$ which is of no interest since the data is unnormalised anyway. Then there is the momentum transfer t to the nucleon which is either limited by the cuts applied in the experimental analysis or the kinematic limits $t_{\mathrm{min}}(m_{\pi\pi}, q_{\mathrm{beam}})$ and $t_{\mathrm{max}}(m_{\pi\pi}, q_{\mathrm{beam}})$, which will produce a different shape by reducing the momentum transfer range in a $m_{\pi\pi}$ dependent way. We find that for the data considered ($q_{\mathrm{beam}} = 18.3, 38.0, 100.0$ GeV) this effect only shows up at invariant two pion masses $m_{\pi\pi} >\approx 1.8$ GeV which is anyhow to high to be dealt with in our model. When we compare our model and the three data sets of GAMS 38 GeV [4], GAMS 100 GeV [5] and BNL 18.3 GeV [2] in the case of low momentum transfer to the nucleon $0.01 < -t < 0.2$ GeV^2 we find good agreement except for the GAMS 38 GeV data deviating just below $m_{\pi\pi} \approx 1$ GeV and above $m_{\pi\pi} \approx 1.3$ GeV. In the high momentum transfer range the experimental t binnings do not coincide but we can at least join some bins to guarantee a common lower limit which is where most of the production should take place anyway. We find that although our model can reproduce the high momentum transfer $0.3 < -t < 1.5$ GeV^2 data of BNL it strongly overestimates the $0.3 < -t < 1.0$ GeV^2 GAMS data. Instead of attributing this to a strong production of high invariant two pion masses $1.1 < m_{\pi\pi} < 1.4$ GeV in the momentum transfer range $1.0 < -t < 1.5$ GeV^2 one should take a revealing look at the momentum transfer range $0.3 < -t < 0.4$ GeV^2. Here data from both experiments is available. One finds that already at those momentum transfers there is a discrepancy between the data sets. Adjusting the parameters of the high lying f_0' confinement pole there is no problem to describe the full t range of the GAMS data. Since the parameters of the f_0' influence the physics around $m_{\pi\pi} \approx 1$ GeV a precise measurement of high resolution close to threshold $K\bar{K}$ scattering data would be highly appreciated. This is especially true since the physics of the f_0' differs considerably between different models where anything from a strong admixture to the $K\bar{K}$-molecule [6] down to a very tiny contribution which finetunes the pole position [7] is possible. Another way to extract information on the structure of the $f_0(980)$ and the admixture of the f_0' to it is suggested in [8] where the authors investigate the lifetime of kaonium. Using a non-relativistic effective field-theory approach they come to the conclusion, that the life time of kaonium depends strongly on the

scattering length in the $K\bar{K}$-channel which in turn constrains the structure of the $f_0(980)$ resonance. So a lifetime measurement of kaonium and a close to threshold measurement of $K\bar{K}$ production are promising ways to put constrains on the nature of the $f_0(980)$.

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10.4 Classification of $a_0(980)$ and $f_0(980)$

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When two scattered mesons are coupled to a resonance in the interaction region, the scattering cross section for the process shows a peak near the mass of that resonance. This can be described by a pole in the scattering matrix $S(E)$, at a complex value of the total invariant mass E. However, when the two scattered

mesons are coupled to a confined system, with an infinite spectrum of resonant states, then, besides an infinity of complex-energy poles near the masses of the confinement states, the scattering matrix also contains poles of a different origin. In general, the latter phenomenon yields no visible signals in the scattering data, since these poles are far away from the real E axis. But in some cases their effects can be measured in experiment. The low-lying scalar mesons $\sigma(600)$, $\kappa(800)$, $a_0(980)$, and $f_0(980)$ represent an example of such observable effects in elastic and inelastic meson-meson scattering [1]. Other examples are the broad $D(2290)$ and narrow $D_s(2317)$ charmed scalar resonances [2].

The S matrix for the scattering of meson pairs which in the interaction region are coupled to an infinite spectrum of confinement states can be straightforwardly modelled, at least for low energies [3]. In the case of elastic scattering one obtains [4]

$$\left\langle \vec{p}\,|T|\,\vec{p}\,'\right\rangle \;=\; \frac{\lambda^2}{4\pi}\sum_{\ell=0}^{\infty}(2\ell+1)\;P_\ell\left(\hat{p}\cdot\hat{p}\,'\right)\;\frac{\displaystyle\sum_{n=0}^{\infty}\frac{\mathcal{J}^*_{n\ell}(p)\mathcal{J}_{n\ell}(p')}{E(p)-E_{n\ell_c}}}{1+i\pi\lambda^2\mu p\left(\dfrac{\lambda a}{\mu_c}\right)^2\displaystyle\sum_{n=0}^{\infty}\frac{\mathcal{J}^*_{n\ell}(p)\mathcal{H}^{(1)}_{n\ell}(p)}{E(p)-E_{n\ell_c}}}\quad .$$

For this expression one can study the pole structure and the related observable signals. In Ref. [5] it is shown why the $a_0(980)$ and $f_0(980)$ scalar resonances are of exactly the same nature as the $\sigma(600)$ and $\kappa(800)$.

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10.5 Scalar Mesons and instanton induced Quark Forces

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The theory of instantons is reviewed and the canonical instanton induced force is derived. To demonstrate its effect, this force is studied within a relativistic quark model. The mass pattern of the pseudoscalars naturally arises and the $U_A(1)$–problem is solved. For scalar mesons the force changes sign and produces a low–lying flavor–singlet. It is discussed how this pattern fits into a dynamical calculation with additional dynamical resonances.

11 Mesonic Bound States

Convenor: A. Gillizer

11.1 Mesonic Bound States

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The cleanest experimental access to the in-medium properties of hadrons is opened in the study of bound or quasi-bound states of these hadrons with nuclei. The power of this experimental approach has been demonstrated in the study of deeply bound states [1]. In this way well-defined spectroscopic information has been obtained for negative pions in deeply bound $1s$ states of Pb and Sn nuclei. These pionic states may be understood as nuclear halo states with significant overlap of the pion and nuclear density distributions, forming an environment which is the closest possible approach to the ideal case of "real" pions in nuclear matter at rest.

The strength of the s-wave potential is with good accuracy determined by the $1s$ binding energy and width. In comparison to the data on $1s$ states in light symmetric nuclei, the new information from $1s$ states in heavy nuclei allows to separate the isovector from the isoscalar part. A significant enhancement of the repulsive isovector strength as compared to the free pion-nucleon interaction, as determined precisely in the study of pionic hydrogen, was observed. To the lowest order the isovector s-wave πN interaction is directly related to the pion decay constant f_π which is the order parameter of chiral symmetry breaking of QCD. The deduced strength of the in-medium isovector πN interaction may be interpreted as a reduction of the chiral $\overline{q}q$ condensate by 22% at the density probed by the π^- ($\sim 0.6\rho_0$).

Possibilities are open for future experimental studies of meson nuclear bound states at COSY. Nuclear bound states may exist for η, ω, and $K^-/\overline{K^0}$ mesons. A study of the η-^{3}He system at the TOF detector has been proposed [2] and a first exploratory

measurement was already done. The anomalously high η production cross section observed previously in the reaction $pd \to {}^3\mathrm{He}\eta$ has been interpreted as a consequence of the existence of a quasi-bound state in the η-^{3}He system. The strategy of the TOF experiment is based on the expectation that, in case such a bound state is formed in pd collisions, the η meson will be predominantly absorbed in the $\eta N \to \pi N$ channel. η absorption on a neutron will then result in a peculiar final state consisting of a $p\pi^+$ pair back-to-back in the cm frame and a spectator di-proton traveling at cm velocity. The same technique can also be employed in order to search for a quasi-bound ω-^{3}He state.

Large attractive potentials have been also predicted for antikaons in nuclear matter. There are indications for a significant attractive in-medium potential from heavy-ion collisions, but the interpretation is strongly model-dependent. This issue may be resolvable in the future only in the search for and study of nuclear bound states of antikaons. The usage of K^- beams seems to be the most direct way to populate such states, but the availability of good quality K^- beams in the future is uncertain. The usage of proton beams does not allow the population of bound $\overline{K}$ states without momentum transfer, but if the binding is strong enough bound systems might nevertheless be formed. A possible experiment could be the search for the reaction $p + {}^4\mathrm{He} \to \overline{K^0} \otimes {}^4\mathrm{He} + K^0 + p$ with $K^0 \to \pi^+\pi^-$ and $\overline{K^0} \otimes {}^4\mathrm{He} \to \Lambda pd \to p\pi^- pd$. A new magnetic 4π detector with charged particle (K^+) identification would allow the even more promising search for a bound $K^- \otimes {}^3\mathrm{He}$ system.

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11.2 The New Pionic-Hydrogen Experiment at PSI: First Results

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In pionic hydrogen the hadronic pion–nucleon interaction manifests itself by a change of binding energy and natural line width of the atomic s states. Experimentally accessible are X–ray transitions to the 1s ground state emitted in the last de–excitation step of the atomic cascade. In the framework of $Heavy - Baryon\, \chi PT$, 1s–level shift ϵ_{1s} and width Γ_{1s} are given unambiguously by the isoscalar and isovector scattering lengths a^+ and a^- [1] by Deser–type formulae [2]. Furthermore, from the isovector scattering length the pion–nucleon coupling constant is obtained by means of the Goldberger–Miyazawa–Oehme sum rule [3].

To improve on the accuracy for ϵ_{1s} and Γ_{1s} as compared to previous measurements [4], a thorough study of a possible influence of de–excitation processes during the atomic cascade is essential. A first series of measurements has been completed by the new pionic–hydrogen experiment at the Paul–Scherrer–Institut (PSI), using the new cyclotron trap, a cryogenic target and a Bragg crystal spectrometer equipped with spherically bent silicon and quartz crystals and a large–area CCD array [5].

To identify radiative de–excitation of the πH system – when bound into complex molecules formed during collisions $\pi^- p + H_2 \rightarrow [(pp\pi^-)p]ee$ [6] – the $\pi H(3p - 1s)$ transition energy was measured in the density range from gaseous H_2 of 3.5 bar to liquid. X–ray transitions from molecular states should show up as low–energy satellites with density dependent intensities. No density effect could be established and it is concluded that the decay of molecules is dominated by Auger emission. The new (preliminary) value of $\epsilon_{1s} = 7.120 \pm 0.008\, ^{+\,0.009}_{-\,0.008}$ eV for the hadronic shift [7,8] is in agreement with the result of the previous experiment [4].

At present, the accuracy for the hadronic broadening (7% [4]) is limited by a not precisely known correction to the measured line width originating from the Doppler

broadening due to Coulomb de–excitation. For that reason the precisely measured 1s–level shift in pionic deuterium was used together with the shift of hydrogen in the determination of the πN scattering length and the pion–nucleon coupling constant[9]. This procedure, however, requires a sophisticated treatment of the 3–body system πD. In addition, so far it cannot be excluded that the radiative decay channel after molecule formation is strongly enhanced in deuterium compared to hydrogen.

To study the influence of Coulomb de–excitation, the three $\pi H(2p-1s)$, $\pi H(3p-1s)$, and $\pi H(4p-1s)$ transitions were measured. An increase of the line width was found for the $2p-1s$ line compared to the $3p-1s$ transition, which is attributed to the higher energy release available for the acceleration of the πH atom. This result is corroborated by a reduced line width of the $4p-1s$ line. From the $\pi H(4p-1s)$ transition a safe upper limit of 850 meV is determined [8,9]. Data analysis is in progress.

From about 2005 on, Coulomb de–excitation will be studied in detail in the absence of strong–interaction effects by measuring K transitions from muonic hydrogen. Together with the detailed knowledge of the response function by using the ECRIT [10] and a newly developed cascade code [11], which includes the velocity dependence of the atomic cascade, a sufficiently accurate correction for the Doppler broadening in pionic hydrogen should be achieved to extract the hadronic broadening at the level of about 1%.

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11.3 Deeply Bound Pionic Atoms and Chiral Restoration in Nuclei

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A goal of this work is measuring the degree of chiral symmetry restoration in a nuclear medium through the determination of the isovector πN interaction parameter in the pion-nucleus potential by studying deeply bound 1s states of π^- in heavy $N > Z$ nuclei [1, 2, 3, 4]. For that we performed a systematic experimental studies of 1s π^- states in a series of Sn isotopes, which were produced with the Sn(d,^{3}He) reactions. One of the advantages of using Sn isotopes is that we can produce the 1s π^- states as the most dominant quasi-substitutional states, $(1s)_{\pi^-}(3s)_n^{-1}$, because of the presence of the 3s orbital near the Fermi surface, as theoretically predicted [5]. Another merit is to make use of isotopes over a wide range of $(N - Z)/A$ to test the isospin dependence [6].

We observed spectra, $d^2\sigma/dE/d\Omega$, on mylar-covered ^{116}Sn, ^{120}Sn, ^{124}Sn targets as function of the ^{3}He kinetic energy [7]. The overall spectrum shapes for the three Sn targets were found to be in good agreement with the predicted ones [5]. The spectra were decomposed according to the theoretical prescription of Ref. [5],

from which we could precisely determine the 1s binding energies (B_{1s}) and widths (Γ_{1s}). The obtained data of binding energies and widths of the 1s π^- states in ^{115,119,123}Sn combined with those of symmetric light nuclei (^{16}O, ^{20}Ne and ^{28}Si) yielded $b_1 = -0.116 \pm 0.007\ m_\pi^{-1}$ [7].

The magnitude of the observed $|b_1|$ is significantly enhanced over the free πN value [8], which translates into a reduction of f_π^{*2} as [9, 10]

$$R = \frac{b_1^{\mathrm{free}}}{b_1} = 0.78 \pm 0.05 \approx \frac{b_1^{\mathrm{free}}}{b_1^*(\rho_e)} \approx \frac{f_\pi^*(\rho_e)^2}{f_\pi^2} \approx 1 - \alpha\rho_e,$$

where we made use of the fact [11, 12] that the solution with a local-density-dependent parameter, $b_1^*(\rho) = b_1^{\mathrm{free}}/(1 - \alpha\rho(r))$, is equivalent to that using a corresponding constant parameter $b_1 = b_1^{\mathrm{free}}/(1 - \alpha\rho_e)$ with an effective density $\rho_e \approx 0.6\rho_0$.

The above value hence implies that the chiral order parameter, $f_\pi^*(\rho)^2$, would be reduced by a factor of ≈ 0.64 at the normal nuclear density $\rho = \rho_0$. If a theoretical value, $m_\pi^* \approx m_\pi + 3$ MeV (averaged over π^+ and π^- [13]), is inserted into an in-medium Gell-Mann-Oakes-Renner relation [14, 15], $\langle\bar{q}q\rangle_{\rho_0}/\langle\bar{q}q\rangle_0$ will be $(m_\pi^*/m_\pi)^2 \times (1 - \alpha\rho_0) \approx 0.67$, which is in good agreement with the theoretical value of 0.65 [16], as an clear evidence for the partial restoration of chiral symmetry in a nuclear medium.

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11.4 Deeply bound pionic states in $\mathrm{d}^{136}\mathrm{Xe}\rightarrow{}^{135}\mathrm{Xe}_{\pi}{}^{3}\mathrm{He}$ at CELSIUS

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In experiments at the CELSIUS accelerator and storage ring[1] we are studying the possibility to produce and to investigate in detail deeply bound pionic states of xenon in order to obtain information on pion properties in the nuclear medium. The existence of relatively narrow deeply bound pionic states in heavy nuclei has been predicted theoretically [2] and the observation of a peak corresponding to the $2p$ state of the ^{207}Pb pionic atom [3] has been reported. Recently the production of the $1s$ state in ^{205}Pb was also observed [4]. These experiments confirmed that, in the case of a lead target, the probability to populate atomic $2p$ states is large compared to that for populating the $1s$ state, due to the lack of s-state neutrons in the outer nuclear shell. For xenon the outer neutron shell contains s-state neutrons and a relative increase in the population probability of the $1s$ pionic-atom state is expected. The closed shell nucleus ^{136}Xe is suggested, by Umemoto et al. [5], to be a particularily good candidate as a target for the observation of deeply bound $1s$ states in (d,^{3} He) reactions.

Here we report results of an investigation of the production of pionic atoms of xenon in (d, ^{3}He) reactions using natural xenon as a target [6] and a status report on the experiment using an isotopically pure gas of ^{136}Xe. The production of the pionic $1s$ state in xenon is observed in both experiments.

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11.5 Chiral Dynamics of Deeply Bound Pionic Atoms

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We present a systematic calculation, based on two-loop chiral perturbation theory, of the pion selfenergy in isospin-asymmetric nuclear matter [1]. A proper treatment of the explicit energy dependence of the off-shell π^- selfenergy together with (electromagnetic) gauge invariance of the Klein-Gordon equation turns out to be crucial for description of the deeply bound pionic atom states [2]. The minimal replacement $\omega \to \omega - V_c(r)$, with $V_c(r)$ the (attractive) Coulomb potential, in the ω-dependent π^- selfenergy generates effectively a large part of the "missing" s-wave repulsion. Accurate data for the binding energies and widths of the 1s and 2p states in ^{205}Pb, ^{207}Pb and several Sn-isotopes are well reproduced. The connection with the in-medium change of the pion decay constant f_π is clarified. At leading order the energy dependence effects can be interpreted in an equivalent energy independent optical potential in terms of a reduced in-medium pion decay constant $f_\pi^*(\rho)$.

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11.6 Search for Eta–Nucleus Bound States at Big Karl, COSY

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The idea that the eta meson can form a bound system with nucleus was first put forward long ago by Peng[1] and also by Liu[2] and was based on the observation of Bhalerao & Liu[3] that the low energy eta-nucleon interaction is attractive. Since then a number of calculations have been performed to predict binding energy and width of eta-nucleus bound system. Such a quasi-bound system (known as eta-mesic nucleus) if exists, can be a very useful tool to investigate eta-nucleus interaction. At the experimental side, a few attempts were made to look for the existence of such systems but have failed, so far, to reach any conclusive direct evidence. At COSY, we have a dedicated experimental programme on the investigation of eta-nucleus interaction. In one part of the programme, the eta-nucleus quasi-bound states will be studied employing the magnetic spectrometer BigKarl and a large acceptance plastic scintillator detector ENSTAR. The reaction proposed to be studied is p+A$\rightarrow$^{3}He+(A-2)$_\eta$ at recoil free kinematics. ^{3}He will be detected by BigKarl while the decay products of "eta-mesic nucleus", namely, protons and pions will be registered at ENSTAR. The coincidence measurement between BigKarl and ENSTAR is expected to enhance sensitivity of the measurement. The detector ENSTAR [4, 5] which has been built at BARC, Mumbai, is in its final stages of fabrication at Juelich and will be tested in fully assembled conditon at COSY in March 2004. The data taking measurement will then follow.

The other part of the programme focuses eta-production in a nucleus (not necessarily through the bound state formation) e.g., p+^{6}Li$\rightarrow$^{7}Be+η. In this case, the heavy recoil nucleus ^{7}Be will be detected at the focal plane of BigKarl and eta-production

events can be identified by missing mass method. In order to improve position resolution necessary for such a measurement, a multi-wire avalanche counter(MWAC) which functions at relatively low pressure will be used. Such a MWAC has been constructed and testing of the chamber is in progress.

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11.7 The $\eta - 3N$ system

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Low-energy interaction and photoproduction of η mesons on three-body nuclei is considered [1]. The model containing 4-body scattering approach to the $\eta - 3N$ system does not predict existence of the $\eta 3N$ bound states. Strong rise of the η yield observed in experiments just above threshold is a consequence has to be ascribed to the virtual $\eta 3N$ state. Only with $\Re e a_{\eta N}$ more than 1 the bound state may be generated. The energy dependence of the cross section, which is determined by the low-energy parameters of the η^3He elastic scattering agrees quite well with that observed in the *pd* collision. On the other hand the magnitude as well as the form of the experimental cross section for ^{3}He$(\gamma, \eta)^3$He presented in [2] is not explained.

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11.8 Photoproduction of η mesic ^{3}He

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In recent years, a lot of effort has gone into the investigation of possible quasi-bound states of η mesons and nuclei - so-called η mesic nuclei. Determinations of the η-N scattering length [1] suggest a strong attraction of the η meson and nuclei that might result in quasi-bound states even for light nuclei [2] like ^{3}He. However, up to now there is no solid experimental proof for such states neither for light nor for heavier nuclear systems, although recent investigations of ^{11}B seem to show indications for a bound state [3]. In the present experiment, the possible existence of an η mesic nucleus is investigated via the η photoproduction from ^{3}He. The experiment has been carried out at the MAMI accelerator facility in Mainz [4, 5] with real photons up to an energy of 820 MeV using the TAPS detector system [6]. Two decay channels of η mesic ^{3}He have been considered and compared to each other: the decay into the coherent η channel and the competing decay into π^0pX. In the latter case, the relative opening angle of the π^0-proton pair is expected to be near 180° for the decay of an η mesic state. The excitation functions for both decay channels show a structure near $\sqrt{s}$=1485 MeV indicating the existence of a bound η-^{3}He state. This conjecture is supported by the measured angular distributions while theoretical calculations [7, 8, 9, 10, 11] for the coherent η cross section fail to reproduce the measured distribution.

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12 pn induced Reactions

Convenors: R. Schleichert and C. Hanhart

12.1 Nucleon-Nucleon (NN) Elastic Scattering

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The large amount of recent data by the NN programs at PSI [1], SATURNE II [2], the PINTEX experiment at IUCF [3], and EDDA at COSY [4] has helped to improve and extend phase-shift parameterizations [6] of the world NN database and has set tight limits on the coupling of dibarionic resonances to the isovector NN channel [5]. Up to about 1 GeV precise phase shifts and scattering amplitudes have been obtained unambiguously, while at higher energies PSA solutions tend to disagree [6] and various sets of amplitudes fit the data [4]. Above 1.1 GeV np data is scarce, especially double-polarization observables and phase shifts are practically unknown. However, phase shift parameters of certain partial waves are crucial in describing the initial state interaction and thus the scale of the total cross section in near-threshold meson production [7]. Here, COSY could further contribute to the pp data base by measuring certain triple-spin observables which would resolve the remaining ambiguities even with moderate experimental precision. For quasi-free scattering of protons on vector-polarized deuteron targets – where the proton in the deuteron acts as a spectator – seems to be the most promising way to access np spin observables at COSY in the near future [8]. A detector for low-energy spectator protons has already been developed [9]. Quasi-free data in meson production and pp and np elastic scattering at CELSIUS and SATURNE [10] indicate that the spectator model may be valid at COSY energies over a sizeable angular range.

On the theoretical side chiral perturbation theory has has been pushed to fourth order in the chiral extension and a description of the NN database up to 300 MeV (e.g.

[11]) almost comparable to high precision potentials has been achieved. Above the pion-production threshold at 300 MeV meson-exchange models, where the inelasticity is introduced by coupling to the NΔ- and $\Delta\Delta$-channels, give a fair description of the data up to 1 GeV [12]. However, these models fail badly in the 1-3 GeV range, which may not be surprising due to the large number of other resonances not included in the model. Only recently theoretical work has started, taking up the challenge of describing NN scattering in the resonance region.

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12.2 Introduction

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12.3 PN versus PP induced production reactions

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Meson production in nucleon-nucleon collisions is a rather attractive research field in hadron physics at intermediate energies. One of the main questions to be answered in the investigation of the reactions $NN \to NNM$ is the dominant mechanism for the production process. For example, the understanding of the mechanism of meson production in NN-collisions could help to pin down the special features of baryonic resonances involved in the production process. Also these reactions may be used as a tool for the investigation of the NN and MN interactions, in particular as a test for existing NN and MN-models.

Note that so far the most efforts both of the theory and experiment are focused on the study of the isotriplet channel, i.e. on the reactions such as $pp \to NNM$. We would like to stress, however, that the study of the channel with I=0 is not

less important since pn-reactions contain information about the production process complementary to the pp-channel. A good example illustrating the potential of the pn-channel is the cross section ratio $R = \frac{\sigma_{pn \to pnM}}{\sigma_{pp \to ppM}}$. Consider this ratio in the Born approximation and, for example, for the production of isoscalar particles. When isovector meson exchanges dominate in the production process the cross section ratio equals to 5, whereas when the isoscalar exchanges are the most relevant ones the ratio is 1. Thus, the ratio contains information about the production process which can not be extracted if only one of two NN channels is investigated.

However, one has to keep in mind that the ratio depends also on effects of the NN interaction in the initial and final states. Note also that NN FSI and ISI effects are different in different isospin channels. The inclusion of the NN FSI to the ratio is not a problem since NN FSI effects are known rather well in the near threshold region for different produced mesons. The influence of short ranged NN ISI effects is known much worse or not known at all for mesons heavier than η produced in the pn-channel. This problem is due to the lack of the experimental data related to the measurements on the neutron target at high energies, i.e. for pn-scattering. Therefore data on pn phase shifts and inelasticities, which are the direct input for the theoretical models, are available only below $T_{lab} = 1300$ MeV (η threshold corresponds to $T_{lab} = 1250$ MeV). Thus, in order to allow a quantitative investigation of the production of mesons heavier than η one has to improve our knowledge about ISI effects. Therefore new experimental data on pn elastic scattering at higher energies would be very desirable.

In the summary we would like to emphasize that only combined analysis of pp and pn channels might allow to draw conclusions about the mechanisms of production for different mesons. In papers [1, 2] this was done for π and η meson production respectively. It is also worth noting that in a microscopic model calculation such as [1, 2] the cross section ratio results from a rather delicate interplay between several ingredients, in particular the actual production mechanism, effects from the FSI as well as from the ISI and interference effects. This means that one should be very cautious with drawing conclusions on the cross section ratio or other experimental

observables from simpler model analyses when only one or two of those ingredients are considered explicitly.

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12.4 η – meson production and interaction in the 3–N system

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Recent data on the $pp \to pp\eta$ reaction measured by the COSY-11 collaboration and earlier data from experiments at SATURNE and at CELSIUS turned out to be very useful for studies of the η production mechanism in nucleon–nucleon collisions [1,2,3]. In order to study the η production in the three–nucleon system, which is much less explored compared to the two–nucleon case, the COSY-11 collaboration performed measurements of the $pd \to ^3He\eta$ reaction for five excess energies in the range from Q =5 to 40 MeV. The preliminary results for the total cross section are consistent with predictions of the two–step reaction model [4]. Further tests of this model should be possible with data for the $dp \to {}^3He\eta$ reaction which were taken for four excess energies: Q =0.7, 4.0, 6.9, 10 MeV and at present are being analyzed. For simultaneously measured reaction $dp \to {}^3HeX$, a clear peak is visible in the missing mass spectra at the mass of the π^0–meson. This confirms usability of the COSY-11 detection system for measurements of the $dp \to {}^3He\pi^0$ reaction at the η threshold and thus opens the possibility of studying the $\pi^0 - \eta$ mixing [5] and of determining the sign of the ${}^3He - \eta$ scattering length [6].

The COSY-11 system supplemented with a neutron detector and a spectator proton detector was also successfully applied for measurements of the quasi–free $pn \to pn\eta$

reaction with a proton beam scattered on neutrons in a deuteron target. In the next step, it is planned to study the gluon content in the η'–meson wave function by comparison of the ratio $R_{\eta'} = \sigma(pn \to pn\eta')/\sigma(pp \to pp\eta')$ with $R_\eta = \sigma(pn \to pn\eta)/\sigma(pp \to pp\eta)$ as proposed by Moskal [7].

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12.5 $\vec{p}\vec{n} \to pn$ at ANKE

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While for the pp system the situation is fair, the nucleon-nucleon database on pn scattering up to 3 GeV is only scarcely populated. Above about 1 GeV the pn data base is almost empty. The phase shift analyses need to be improved/extended towards higher energies. It should be noted that in order to gain further insight into the NN interaction, *both* isospin channels need to be studied. But for the pn system even the data are missing. A recent theoretical assessment of the situation has clearly shown, that the theoretical understanding of the NN system above 1 GeV is still unsatisfactory [1].

	I	I_3	status
pp	1	1	ok
np	1	0	!
nn	1	-1	?
np	0	1	!

Although the ANKE dipole spectrometer is not ideally suited for polarization experiments because of a lack of azimuthal symmetry, some polarization observables, i.e. analyzing power A_y and one of the four spin correlation coefficients (A_{yy}) could also be measured using the ANKE dipole spectrometer with a vertically polarized polarized hydrogen gas target, bombarded by the polarized proton beam from COSY. In particular at small cm scattering angles below $\theta = 30°$, accessible with ANKE, the *pn* data base is almost empty at all energies [2].

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13 Instrumentation

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13.1 Photon Detection at COSY

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Motivation

Photon detection is a very important tool to obtain information in nuclear physics. Nearly all of the produced neutral mesons ($\pi^\circ, \eta, \omega, \eta', \mathrm{f}_0, \mathrm{a}_0$) have decay branches resulting in multiple photon final states. Large photon detectors have been built at many accelerators and are being operated with great success. However, at COSY-Jülich, such a device is missing up to now. All existing detectors are designed for charged particle detection and, thus, neutral particles are reconstructed via missing mass analysis.

What can be done?

Although direct identification of neutral particles is important, a stand-alone photon detector will be a minor improvement only. In order to get the full power in event reconstruction it has to be combined with a number of other detector modules. The requirements for these modules strongly depend on the physics reactions, a fully universal detector will be hard to realize. Taking into account these boundary conditions, one can think of three different ways to get such a detector system: (i) designing a complete new detector, optimized for use at COSY, (ii) taking over an available 4π detector (like it has been done with Crystal Barrel at ELSA or Crystal Ball at MAMI) or (iii) adding photon detection to an existing installation at COSY.

Photon Detection at ANKE

One accepted proposal for (iii) (COSY PAC #21 [1]) is the extension of ANKE [2] with a large acceptance electromagnetic calorimeter. This combination allows coincidence measurements of charged particles at 0° and neutral mesons decaying into photons, and, thus, is ideally suited for reactions close to threshold, or when one charged particle can be missed. Since the time this proposal has been submitted, various R&D studies were done in order to meet the requirements given by the ANKE setup, namely the available space, the stray magnetic field and the compatibility with other installations at ANKE. The result is a detector based on $PbWO_4$ crystals read out by shielded fine-mesh photomultipliers (e.g. Hamamatsu R5505). The next steps would be the final overall design and starting the construction.

Conclusions

There is common agreement that photon detection has to be exploited at COSY. There is an existing proposal for a dedicated photon detector at ANKE, and, furthermore, realization can start soon. However, there might be the possibility for a more general solution. Recent discussions have indicated that the CELSIUS ring (Uppsala) may terminate operation within the next few years. At the moment negatiations are in progress to study the possibility to have the WASA detector avaible for operation at COSY.

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13.2 Silicon Microstrips

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13.3 A Large Tracking Detector with Self-Supporting Straw Tubes

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A novel technique to stretch the anode wire inside drift tubes (straws) simply by the gas over-pressure will be presented. Combined with a dedicated gluing method of the single straws to close-packed double-layers, large but self-supporting detector planes can be built. No heavy end or support structures are needed reducing the overall detector weight to an absolute minimum, allowing a clean and background-free, highly transparent tracking.

The detector will consist of more than 3000 straws filling up a cylindrical tracking volume of $1m$ diameter and $30cm$ length, close behind the target in the COSY-TOF barrel. Each straw tube consists of a $30\mu m$ thick mylar film with a length of $1m$ and $10mm$ diameter, the tubes inside being aluminised to be used as cathode. In the tube centre a $20\mu m$ thick W/Re wire is used as anode. Cylindrical end plugs made from ABS close the tubes at both ends.

The projected spatial resolution of $200\mu m$ for a 3-dimensional track reconstruction allows to resolve the target interaction point with sub-mm precision. The chosen granularity (straw diameter) of $10mm$ provides an almost continuous tracking with up to 30 hits for a precise reconstruction of complex track patterns like the Λ decay ($c\tau \simeq 8cm$) and polarisation by its p and π^- decay tracks. The detector with a total mass of less than $15kg$ will be operated in vacuum, but will have an added wall thickness of 3mm mylar, only.

Detector design, production experience and first results will be discussed.

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13.4 The Crystal Barrel Detector

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From 1989-1996, the Crystal-Barrel spectrometer [1] was used at the Low-Energy Antiproton Ring (LEAR), CERN, to study the products of $\overline{\mathrm{p}}\mathrm{p}$ and $\overline{\mathrm{p}}\mathrm{d}$ annihilations. One goal was to investigate the annihilation dynamics in the non-perturbative regime of QCD. On the other hand, spectroscopy of light mesons was succesfully carried out and new particles were discovered, the scalar meson $\mathrm{f}_0(1500)$, for instance.

In 1997, the Crystal-Barrel calorimeter was moved to Bonn. Since that time, it has formed the basis of a new experimental setup in order to carry out baryon spectroscopy in photoproduction experiments at the Electron Stretcher Accelerator (ELSA). The general idea of the experiment is to use the barrel in combination with suitable forward detectors. In a first series of experiments, Time-Of-Flight walls were used in order to measure meson production directly at threshold. At present, the TAPS detector is operational in current experiments. The latter has fast trigger capabilities to cope with high photon rates and provides high granularity in the forward direction. The total setup covers almost 4π solid angle, thus is an ideal configuration in order to measure multi-photon final states over the full dynamical range. In 2002/2003, data with linearly polarized photons have been taken off the proton as well as off the neutron with the Crystal-Barrel detector and TAPS in the forward direction.

The Crystal-Barrel is a modular electromagnetic calorimeter consisting of 1380 elements. The CsI(Tl) crystals, 30 cm long corresponding to 16.1 radiation lengths, are each viewed by a single photodiode mounted on the edge of a wavelength shifter

placed on the rear end of the crystal. This configuration improves the light collection between the output of the CsI crystal and the photodiode. Each crystal covers 6° in θ (polar angle) and 6° in ϕ (azimuthal angle) except for the two sets of three layers closest to the beam axis where the angular acceptance is increased to 12° in ϕ. The range of polar angles covered by the complete calorimeter is $12^\circ \leq \theta \leq 168^\circ$. In order to make best use of TAPS, the Crystal-Barrel was opened downstream ($\pm 30^\circ$), i.e. 3 forward crystal rings were removed.

In Bonn, the Crystal-Barrel readout electronics is based on a 128-channel-ADC Fastbus system. Readout software was developed which was optimized for high data rates, thus to allow for large amount of data in cooperation with the data aquisition. In addition, the calorimeter is part of the second-level trigger. Based on a discriminator signal from each crystal (threshold 15 MeV), a cellular logic, a fast cluster encoder (FACE), is able to count clusters and, therefore, to trigger on chosen multiplicities of real photons within ≈ 4 μsec.

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13.5 Pellet Target*

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he ANKE pellet target is being developed to study reactions with meson production and cross sections less then 0.1 μb in *pp*, *pn*, *pd* and *dd* collisions [1]. It is expected to reach luminosities higher than $L = 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ with standard COSY beam conditions (proton beam intensity of a few times 10^{10}).

The target consists of the following parts [2]: a cryostat for the production of solid hydrogen (or deuterium) pellets; a dumping cryostat for the collection of the

pellets; a vacuum system; gas supply systems (hydrogen, nitrogen and helium); temperature and pressure control systems.

The upper part of the cryostat contains a system of heat exchangers, which provide a stable stream of liquid H_2 at given values of temperature and pressure. The cooling materials are liquid N_2 and evaporated liquid He. There are three stages of H_2 cooling. First, H_2 is cooled by liquid N_2 down to 100 K. Then the H_2 is cooled down to 22 K in an coaxial-tube heat exchanger by He gas coming from the condenser. The final cooling and transformation into the liquid H_2 is performed in the condenser with the help of cold He gas.

The liquid hydrogen jet is produced with a 60 μm nozzle inside the triple point chamber (TPC). The temperature of the condenser channel and the TPC must be close to the triple point value (T_{tr}=14 K, $p_{tr} \sim 100$ mbar) with an accuracy of not less than 0.1 K. The liquid hydrogen jet is broken into microdroplets of about 70 μm diameter by acoustic excitation. The piezo-electric generator with a resonance frequency of 3 kHz is mounted coaxially at the side of the nozzle.

Behind the TPC the hydrogen droplets pass into two vacuum chambers, in which the pressure is reduced from 100 mbar (triple point value) down to 10^{-7} mbar (COSY ring pressure). During flight through the vacuum the droplets freeze and a continuous flow of frozen hydrogen pellets is formed.

In the moment all main parts of the pellet target are produced and assembled. The target has been installed at a test place in the COSY hall and operates in tests since May 2001. The necessary values of temperatures and pressures can be kept stable for a long time. The production of the stable liquid hydrogen jet and splitting this jet into droplets has been achieved.

The next main step is to pass droplets into the vacuum chambers through sluices of 0.6 mm diameter. For this purpose the adjusting systems for the sluices are under construction. First pellet production is foreseen for test in autumn 2003.

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13.6 Cluster Target

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13.7 Polarized Internal Target and Lamb-Shift Polarimeter at ANKE

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The following components for the polarized internal gas target at ANKE have been built and tested:

1. The polarized atomic beam is produced by an ABS [1]. The intensity of this source is about 7.6×10^{16} atoms/s for hydrogen with a polarization of $-0.97 \leq p_z \leq +0.91$. Atomic beams with atoms in any single hyperfinestate can be produced. The beam profile ($\sigma = 3.6$ mm) is rather small.
   With this high intense beam a target density up to 1×10^{14} atoms/cm^2 can be expected in a storage cell.

2. With a Lamb-shift polarimeter [2] it is possible to measure the occupation numbers of the single hyperfine states in an atomic beam of hydrogen or deuterium. For the full atomic beam of the ABS it takes only 2 s to measure the polarization with an error of less than 1%. When only a small fraction (10^{-4}) of the beam intensity is extracted from the storage cell, the background dominates the measured signal. With a new getter pump in the ionizer of the Lamb-shift polarimeter this background will be decreased substantially and the polarimeter can be used to measure the polarization of atoms effusing from the storage cell.

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13.8 Solid Polarized Target

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14 HESR

Convenors: R. Maier and H. Ströher

14.1 The New Research Facilities at GSI

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14.2 HESR-Design

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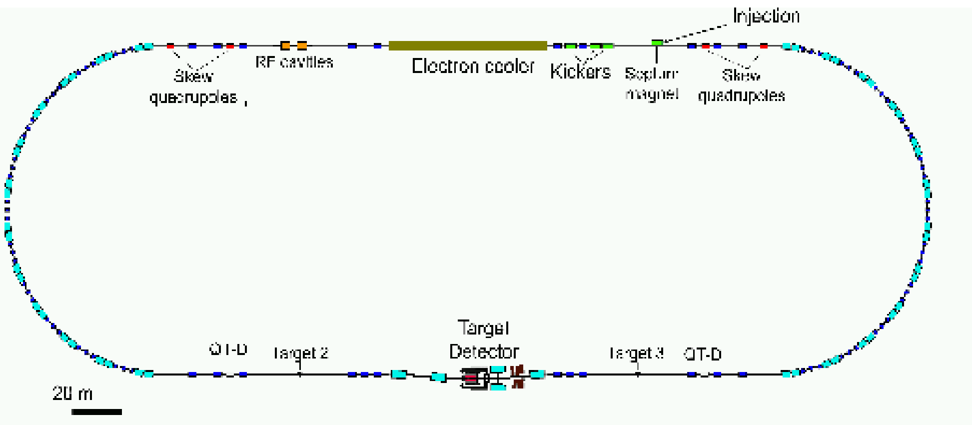
A major objective of the new beam facility proposed by GSI [1] is a High Energy Storage Ring (HESR, [2]) for high luminosity internal target experiments with stored and cooled antiprotons in the momentum range 0.8-14.5 GeV/c (see figure). The concept includes suitable accelerator/storage ring designs as well as adequate techniques for efficient production, fast stochastic cooling and accumulation of antiproton beams. It must fit properly into the complete project: optimal efficiency and extensive time/instrument sharing with heavy ion acceleration and rare isotope beam production. A new linac has to be developed delivering 70 MeV protons with pulse currents of 70 mA, 0.1 ms pulse length and 5 Hz repetition frequency for injection to the existing SIS18. The latter shall l serve as energy booster for a new, fast cycled 100Tm synchrotron accelerating 2.8×10^{13} protons per cycle to 29 GeV. A net accumulation rate of about 1×10^{8} antiprotons every 5 s should allow for experiments at correspondingly high luminosity of up to $2 \times 10^{32} cm^{-2} s^{-1}$.

The lattice design of the HESR provides a race-track shaped ring with superconducting arcs and two approximately 120 m long straight sections. One of straight sections is required for the installation of an electron cooling device of about 30



Plan view of the HESR.
Target 2 and Target 3 could be considered as optional locations for additional internal targets.

m length capable provide cooled antiproton beams over the full energy range [3]. Stochastic cooling might be considered as an complementary installation or as a fall-back option. Internal target experiments with one or two target positions and large detectors are foreseen at the other long straight section. Recent results of numerical calculations of equilibrium beam properties taking into account intra-beam scattering, internal target effects and electron cooling give hope that beam heating might be compensated by means of the proposed EC-device [4]. Investigations of collective beam effects due to space charge and beam-wall coupling are underway.

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14.3 Spectroscopy in the Charm domain

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Experiments with antiprotons at LEAR and Fermilab have started a new era in hadron spectroscopy. Candidates for bound states with gluonic degrees of freedom were found and the spectroscopy in the charmonium region has reached a new level of precision. It is planned to extend measurements of this kind at GSI/Darmstadt. Antiprotons with energies up to 15 GeV will interact with a Hydrogen cluster target in a storage ring (HESR) with high luminosity. The charged and neutral reaction products will be registered in a 4p-detector (PANDA). The talk gives an overview on the physics program envisaged for HESR/PANDA as far as experiments on H2-targets are concerned. The experiments with nuclear targets are discussed in [1]. Fig 1 gives on overview on the QCD-systems, which can be studied.

Production rates for different kinds of particles are given in Table 1.

Some physics highlights are discussed more in detail Precision measurements in the Charmonium system. In contrast to e+e–experiments all states are accessible in formation processes allowing very good mass resolutions Search for Charmed Hybrids These states are expected in the mass range above 3.9 GeV/c2. Some of them will have spin exotic quantum numbers, particularly the ground state (JPC = 1-+) Search for Heavier Glueballs These states are expected in the energy domain up to 5 GeV/c2. Some of them may be narrow because of quantum number conservation. They would be searched for in exotic channels like ff or fh. Spectroscopy of systems with Open Charm Recently, a narrow -state has been seen by BaBar (later confined by Belle and Cleo) with an unexpected mass, making it a good

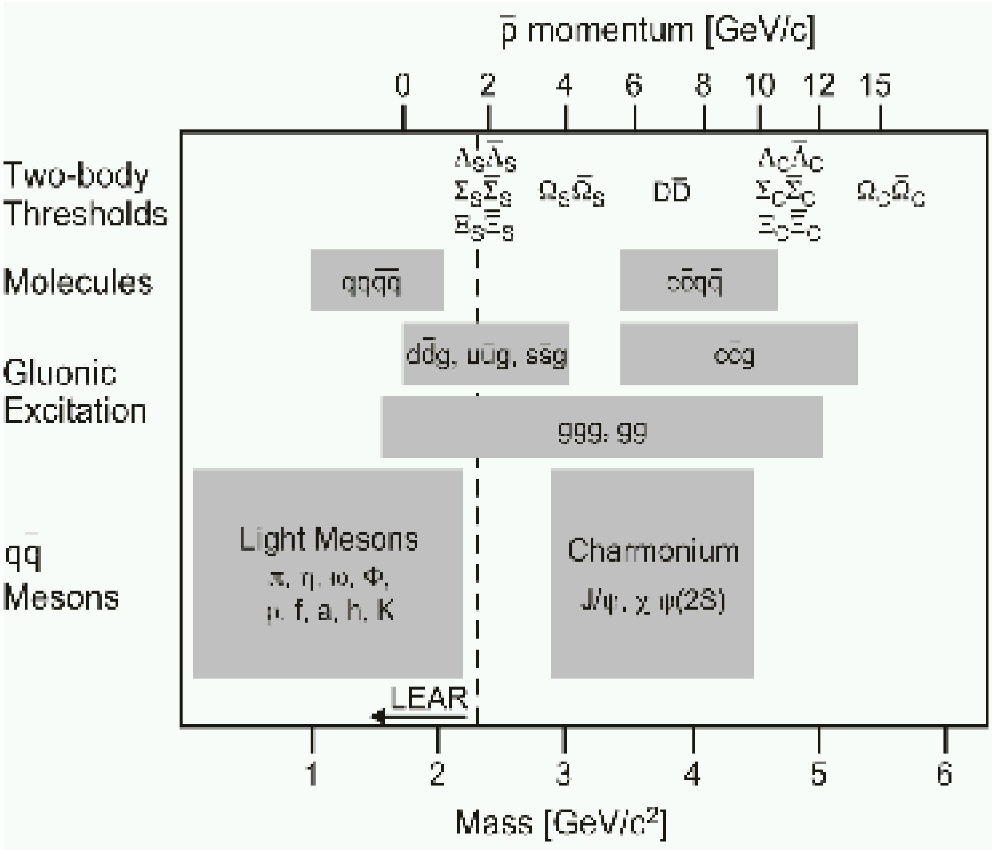

Figure 2: Overview on QCD systems

Final State	cross section	#reconstr. Events/y
Meson resonance + anything	100 μb	10^{10}
	50 μb	10^{10}
	2 μb	10^{8} (10^{5})
	250 nb	10^{7}
	630 nb	10^{9}
	3.7 nb	10^{7}
	20 nb	10^{7}
	0.1 nb	10^{5}

Table 1: *Production cross sections and event rates per year for selected final states*

candidate for a charm-exotic state, e.g. a DK-molecule. More states of this kind are expected to exist and can be seen in -induced reactions. Further options of the program are Spectroscopy of Charmed Baryons Direct CP-violation in the Charm sector Reversed Deeply Virtual Compton Scattering For more details of the physics program see references [2,3], for more details on the PANDA-Detector see [4].

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14.4 Charm in the Medium

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15 Hyperon–Nucleon Interaction

Convenors: J. Haidenbauer and W. Eyrich

15.1 Prediction and Discovery of a Pentaquark Baryon

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15.2 Hyperon-nucleon interaction

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The hyperon-nucleon (YN) interaction is an ideal testing ground for studying the importance of SU(3) flavor symmetry breaking in hadronic systems. Existing meson exchange models of the YN force usually assume SU(3) flavor symmetry for the hadronic coupling constants, and in some cases [1, 2] even the SU(6) symmetry of the quark model. The symmetry requirements provide relations between couplings of mesons of a given multiplet to the baryon current, which greatly reduce the number of free model parameters. Specifically, coupling constants at the strange vertices are connected to nucleon-nucleon-meson coupling constants, which in turn are constrained by the wealth of empirical information on NN scattering.

Indeed SU(3) symmetry was invoked for the construction of basically all YN models that one can find in the literature. One should note, however, that the various models differ dramatically in their treatment of the scalar-isoscalar meson sector, which describes the baryon-baryon interaction at intermediate ranges. For example, in the Nijmegen models [3, 4] this interaction is generated by the exchange of a genuine scalar meson SU(3) nonet. The Tübingen model [5], on the other hand, which is essentially a constituent quark model supplemented by π and σ exchange at intermediate and short ranges, treats the σ meson as an SU(3) singlet.

In the YN models of the Jülich group the σ is viewed as arising from correlated $\pi\pi$ exchange. In practice, however, in the old YN models [1, 2] the coupling constants of the fictitious σ meson (with a mass of 550 MeV) at the strange vertices ($\Lambda\Lambda\sigma$, $\Sigma\Sigma\sigma$) are treated as free parameters. A new model, which is presently being developed [6], includes now explicitly correlated $\pi\pi$ exchange.

Despite those differences, however, essentially all YN interaction models can reproduce the existing YN scattering data. This is primarily due to the poor experimental information about the YN interaction. There are very few data available at low energies and, moreover, they are basically all from the 1960's and of rather low accuracy. But even the few new data points that have emerged over the last few years, due to efforts at the KEK facility [7], are afflicted with large error bars and, as a consequence, do not provide better constraints for the existing YN models.

Therefore, we need to look for other reactions/systems which also involve the YN system and, thus, might allow to obtain further information on the YN interaction. One such possibility is offered by the study of hypernuclei. Here some experimental information is already available and especially the lighter nuclei (${}^3_\Lambda$H, ${}^4_\Lambda$H, ${}^4_\Lambda$He) are also accessible to microscopic, i.e. Faddeev-Yakubovsky type calculations [8].

However, I believe that scattering experiments where the YN system is produced in the final state might be the most promising reactions for learning more about the YN interaction. In particular, only here one can study the YN system at very low energies simply by choosing the reaction energy close to the production threshold. The YN system can be produced in a variety of reactions. One can use electromagnetic probes such as in $\gamma + d \to K^+ + YN$ [9] or $e + d \to e'K^+ + YN$ and also hadronic probes like in $K^- + d \to \gamma + YN$ [10], $K^- + d \to \pi^- + YN$ [11], $\pi^+ + d \to K^+ + YN$ [12], $p + p \to K^+ + YN$, or $p + n \to K + YN$. The latter two reactions are the ones that can be studied at the COSY accelerator and there is already a wealth of data available on the pp channel, cf. corresponding contributions of the TOF and COSY-11 collaborations.

Results reported at this workshop by B. Gibson (for $K^- + d \to \gamma + YN$) and A. Gasparyan [13] (for $p + p \to K^+ + YN$) show that by choosing specific kinematics

and observables one can isolate the effect of the final state interaction in the YN system and then extract specific features of the YN interaction such as the (S wave) scattering lengths from the data.

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15.3 Study of the hyperon - nucleon interaction at Cosy-11

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The Σ^0 and Λ hyperon production near the kinematical threshold was studied by the COSY-11 collaboration in $pp \to pK^+\Lambda/\Sigma^0$ reactions. Data points,16 for the Λ and 13 for the Σ^0 channel, were taken in the excees energy range between 0.68 MeV and 59.3 MeV for Λ (2.8 MeV and 59.1 MeV for Σ^0) [1, 2, 3].
The cross section ratio $\sigma(pp \to pK^+\Lambda)/\sigma(pp \to pK^+\Sigma^0)$ below excess energie of about 15 MeV was measured to be about 28 in contrast to a value of about 2.5 determined for various excess energies higher than $Q = 300$ MeV [4]. The ratio for higher energies is in good agreement with the Λ/Σ^0 isospin relation, which is 3.
To explain this unexpected threshold behaviour, various theoretical scenarios within meson exchange models were proposed. Calculations have been performed with pion and kaon exchange added coherently [6, 7] or incoherently [9], including the excitation of nucleon resonances [8, 10] and heavy meson exchange (ρ, ω and K^*) [8]. Although the various descriptions differ even in the dominant basic reaction mechanism, all more or less reproduce the trend of an increase in the cross section ratio in the threshold region. The present data are not sufficient to definitely exclude possible explanations. Further studies e.g. on the other isospin projections will help to understand the threshold hyperon production.
Within the Jülich meson exchange model the cross section ratio $\sigma(\Lambda)/\sigma(\Sigma^0)$ is reproduced by a destructive interference of π and K exchange amplitudes. Calculations of the Σ^+ production in this model predict a factor of three higher cross section compared to the Σ^0 channel for the destructive and a factor of three lower for the constructive interference. Recently the Σ^+ production was measured at the COSY-11 installation via $pp \to nK^+\Sigma^+$ at Q = 13 MeV and Q = 60 MeV [5] in order to check the cross section ratio between Σ^+ and Σ^0 production. Apart from the Juelich model this ratio will also differ strongly if the dominant production

mechanism runs via an intermediate N^* excitation or not.
In the COSY-11 detection setup, the Σ^+ is identified via the missing mass technique, by detecting the remaining reaction products - K^+ and neutron wich will result in an event identification comparable to the Σ^0 channel.

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15.4 The ΛN scattering lengths from production reactions

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Our knowledge about the low-energy ΛN scattering from direct experiments is based on the scarce data set measured in 1960's. This leads to a very large uncertainty in the ΛN scattering lengths. Thus different YN models, which describe the above mentioned experimental data equally well yield the values for the scattering lengths that may differ by a factor of 4 [1, 2].

The way to improve the present situation is to use an indirect information on the ΛN scattering from production reactions. In this work we develop a method for analyzing the production reactions with a large momentum transfer such as $pp \to pK^+\Lambda$. It is based on the dispersion relation technic and uses the well-known fact that in the properly chosen kinematical region the energy dependence of the amplitude is given mostly by the final state ΛN interaction. Our main result can be derived by means of the methods described in [3, 4, 5] and can be represented by a simple formula for the singlet (triplet) scattering length expressed via an integral of the differential invariant ΛN mass spectra with fixed spin in the ΛN system. The novelty of our approach consists in that we take under control all possible theoretical errors appearing due to various simplifying assumptions.

In order to separate the triplet and singlet parts of the ΛN mass spectra we consider the possibility to use polarization observables. It turns out that looking e.g. at the analyzing power or at the transverse double polarization observables enables to exclude the spin singlet contribution for certain angles of the emitted kaon. It is very important that such observables can be measured at COSY. To extract the pure singlet component of the mass spectrum one needs to perform a more complicated experiment involving longitudinally polarized beam and target.

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15.5 $\mathbf{K^- + d \to n + \Lambda + \gamma}$

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Strangeness provides a third dimension in nuclear physics, one that rises above the two-dimensional (neutron-proton) isospin plane. Using the strangeness (flavor) degree of freedom one can test our knowledge (and models) which has been developed over 3/4 of a century from investigations based upon conventional, non-strange nuclear structure and reactions. Do our models extrapolate beyond the isospin plane or are they merely exquisite interpolation tools within that realm?

Charge-symmetry breaking (CSB) is a topic of current interest, as we explore the effect of the u-d quark mass difference at the nonperturbative QCD scales of nuclear physics. CSB produces a ^{3}He/^{3}H binding energy difference of about 100 keV. In comparison CSB in Λ hypernuclei is a factor of 3 larger than that observed in the nonstrange sector, as is evidenced by the $^4_\Lambda$He/$^4_\Lambda$H binding energy difference of some 360 keV. It seems unlikely that the u-d mass difference mechanism dominates CSB in the strangeness -1 sector of Λ hypernuclei.

There exist limited pΛ scattering data. COSY, through the pp $\to$ pΛK$^+$ reaction, can add important low-energy data. However, there are absolutely no $n\Lambda$ scattering data. The stopped K$^-$ reaction K$^-$d $\to$ n$\Lambda\gamma$ [1] offers a means to extract information about nΛ scattering. Its advantage lies in the fact that there are only two strongly interacting particles in the final state of interest. A similar analysis of π^-d $\to$ nnγ [2] was successfully utilized to extract the neutron-neutron scattering length.

A feasibility study for the stopped K^- experiment was made by Gall *et al.* [3], and a theoretical analysis was published in that same time frame [4]. A χ^2 study of the uncertainties in values of the spin-singlet and spin-triplet nΛ scattering lengths extracted from the shape of the photon spectrum has since been performed [5]. This analysis includes a separate investigation of the use of polarization to cleanly separate the scattering lengths for the two spin states.

The work of B.F.G. was supported by the U.S. Department of Energy under contract W-7405-ENG-36.

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15.6 Hyperonproduction at COSY-TOF*

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The associated strangeness production in elementary nucleon-nucleon-induced reactions is studied exclusively at the external COSY beam using the time of flight spectrometer COSY-TOF[1]. The complete reconstruction of all charged particle

tracks allows the extraction of total and differential cross sections and Dalitz plots as well. A special start detector system, which consists of several layers of highly granular detector components, was developed and optimized for precise track reconstruction, both of primary and secondary decay tracks. The design of the COSY apparatus provides the opportunity to cover the full phase space of the reactions from threshold up to the COSY energy limit. The main goal in the investigations of the reaction channels $NN \rightarrow KYN$ is to gain an insight into the dynamics of the $s\bar{s}$-production, which may also be connected with the questions of the strange content of the nucleon. Theoretical access to the reaction mechanisms is gained within the meson exchange model including resonance contributions, final and initial state interaction and other effects based on coupled channel mechanisms.

Especially the reaction channel $pp \rightarrow K^+\Lambda p$ was investigated recently in detail in high statistic runs and delivered precise results which show strong N^* and FSI contribution. Alongside the Λ-production the production of Σ-Hyperons is a further point of interest within the associated strangeness production. Both Σ^0 and Σ^+ production channels have been measured with respect to total cross sections and angular distributions. The verification of observables of different reaction channels at equal excess energies provides a further tool to test model calculations. Moreover the reaction channels $pp \rightarrow K^0\Sigma^+ p$ and $pp \rightarrow K^+\Sigma^+ n$ are of high interest due to a possible exotic pentaquark resonance (Z^+)[2] which might contribute to the production mechanisms.

This talk will focus on the recent results of the TOF experiment on Λ- and Σ-production, especially discussing the strong energy dependent influence of the 1650 and 1710 N^* resonances in the Λ-production channel and comparing them with the actual theoretical calculations [3],[4] within the framework of the meson exchange models. Moreover the status of the search for the exotic Z^+ penta-quark state is presented. An outlook focussing on polarization observables which will be obtained from a very recent run using a polarized COSY beam will be given. Additionally a short discussion on further reaction channels in pn collisions measured in a test run on a deuterium target will finish the talk.

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15.7 Baryons Coupled to Strangeness

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Strangeness production in pN collisions provides an effective tool for investigation the ΛK, ΣK, KN, ΛN and ΣN subsystems and allows to measure the properties of known baryonic resonances as well as to search for new exotic states.

While the coupling of $S_{11}(1650)$, $D_{15}(1675)$, $P_{11}(1710)$ and $P_{13}(1720)$ to ΛK channel is poorly known [1], their coupling to ΣN channel is absolutely unknown experimentally. It is expected [1] that $P_{33}(1600)$, $F_{15}(1680)$, $D_{33}(1700)$ and $F_{17}(1990)$ baryons couple to strangeness, however until now there are no established data. Recently SPHINX Collaboration [2] measured Σ^0K^+ production in pN collisions and detected new baryon with mass M=1995±18 MeV and width Γ=90±32 MeV. The new $X(2000)$ state predominantly decays to strange channels and was considered as an exotic baryon with hidden strangeness. These measurements are accessible at COSY.

The study of KN subsystem produced in $pN \to KNY$ reaction allows to determine the pentaquark properties, and not only its mass and width. The K-meson angular

distribution in Jackson frame is an effective tool to measure the Θ^+ parity, taking into account that the pentaquark production cross section in pN collision is large [3]. Moreover the $pn{\rightarrow}K^0pK^-p$ or $pn{\rightarrow}K^+nK^-p$ reactions are even better suited to Θ^+ measurements, since these reactions are dominated by K-meson exchange, which results in large pentaquark production cross section. The required proton beam energy is $\simeq$2.83 GeV, that is close to the COSY limit, but one can explore the neutron momentum gained from the deuteron target.

The ΛN and ΣN subsystems allow to search for strange dibaryons, the subject being still under controversial discussions [4]. The precise measurements with high intensity beam available at COSY may result either in discovery of strange dibaryon or lead to new upper limit, which is expected to be substantially lower than established presently. Furthermore, the systematic studies of the ΛN and ΣN subsystems provide access to an evaluation of hyperon-nucleon interaction and allows direct measurement of the $\Sigma{\rightarrow}\Lambda$ transition around ΣN production threshold.

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15.8 High Resolution Search for Strangeness -1 Dibaryons

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A high resolution search for the lowest strangeness -1 dibaryons D_s and D_t via p+p→K^++D using COSY and BIG KARL has been started. Quark model calculations [1, 2] predict such states about 55 and 95 MeV above the Λp threshold with invariant masses of 2109 and 2149 MeV and total widths of less than 100 and 800 keV, respectively. The HIRES experiment at COSY refers to a previous SATURNE II experiment [3] where a small and narrow peak at about 2097 MeV was observed in the missing mass spectrum of the reaction p+p→K^++X at proton energies of 2.3 and 2.7 GeV. The new experiment intends improved statistical accuracy and higher missing mass resolution. By this, the sensitivity of the search can be improved by an order of magnitude. Using the spectrometer BIG KARL the outgoing kaons are detected at 0° which is the optimal scattering angle for a reaction with angular momentum transfer $\Delta l = 0$.

The first HIRES run was in April 2003. With a proton beam momentum of 2.730 GeV/c the mean momentum of the outgoing kaons was 0.960 GeV/c. The momentum acceptance of BIG KARL coresponds to a missing mass range of 2.08 - 2.11 GeV. The most important experimental achievement was the particle identification of the kaons against the huge background of pions and protons. We used two new threshold Cerenkov detectors in the focal plane of the spectrometer in order to discriminate pions from kaons. The protons were separated using TOF-information. So, we were able to identify the kaons as a well separated peak in the online TOF spectra gated with the Cerenkov signal. Another important point was the preparation of the proton beam by the COSY team. A careful fine tuning of the socalled stochastic beam extraction was done with the aim of a very high beam momentum resolution (about $3 \cdot 10^{-4}$). The expected missing mass resolution is 350 keV. We achieved rather high beam intensities of about $1.0 \cdot 10^9$ protons/s during extraction corresponding to a time averaged beam intensity of about $0.7 \cdot 10^9$ protons/s. The online missing mass spectrum comprises only a (small) part of the full statistics and it is premature to decide the existence or nonexistence of a sharp resonance near 2100 MeV. The off-line analysis is underway.

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16 Few Nucleon Systems

Convenors: F. Rathmann and N.N. Nikolaev

16.1 Few Nucleon Systems at COSY and short-range NN interaction

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Short-range structure of the lightest nuclei is related to fundamental problems of hadron physics and can be probed in processes with high transferred momentum Q^2. Pure meson-nucleon theory with consistent inclusion of important relativistic contributions works well in case of deuteron elastic formfactors at $Q \leq 1$ GeV/c (i.e., at internal momenta in the deuteron $q \leq 0.5$GeV/c), but gives less clear result at higher Q^2 and fails for high energy deuteron photodisintegration[1]. It is assumed[1], that these data probably indicate for new physics with explicite quark-gluon degrees of freedom in the deuteron at high Q^2. Hadronic processes at special conditions can give a new independent information here.

The reaction $pd \to pp(^1S_0)n$ in kinematics of backward elastic pd scattering at beam energies 1–2 GeV provides a new testing ground for the short-range NN and pd dynamics[2]. In contrast to the elastic $pd \to dp$ process, advantages of the breakup reaction are caused by the isospin state I=1 of the final diproton as compared to the I=0 for the deuteron. The contributions from intermediate states with nucleon resonances (Δ, N^*), which are theoretically not well under control, are essentially suppressed in the $pd \to pp(^1S_0)n$ reaction due to isospin invariance. Another important qualitative feature of this reaction is connected to the fact that at low excitation energy of the two protons, $E_{pp} < 3$ MeV, the spin-singlet s-wave state $^1S_0$ dominates in the final diproton, whereas the deuteron wave function $\psi(q)$ at high q has a large contribution from the d-wave.

Measurements of the spin-averaged cross section of the reaction $pd \to pp(^1S_0)n$ in kinematics of backward elastic pd-scattering have been recently performed at COSY[3] and preliminary data on A_y^p have been obtained. The analysis within the known ONE+SS+Δ model[4] of the $pd \to dp$ process shows[5] that a reasonable agreement with the data can be achieved when a rather soft NN interaction potential at short NN distances ($r_{NN} < 1$ fm) is used for the $^3S_1 -^3 D_1$ and $^1S_0$ states. Therefore, the modern high accuracy CD Bonn NN potential is much more preferable within the ONE+SS+Δ model in contrast to the RSC or Paris potentials. In order to test this picture, spin observables (analyzing powers A_y and T_{20}, spin correlations $C_{y,y}$, $C_{z,z}$ and $C_{xy,z}$) are calculated here and planned to be measured at COSY. The main question to experiment is whether the $T_{20}(\theta_{cm} = 180°)$ changes its sign at beam energy $T_p > 1$ GeV as it follows from this model, and others spin observables exhibit remarkable features[2] caused by the node in the half-off-shell pp($^1S_0$) scattering t(q)-matrix at $q \approx 0.4 GeV/c$. Role of initial and final state interaction effects and relativistic P-wave components of the deuteron and diproton are briefly discussed.

Using more heavy target allows us to probe more high internal momenta q in nuclei at the same beam energy. So, according to Ref.[6], the cross section of the p^{3}He→^{3}Hep process probes the ^{3}He wave function at high internal momenta q=0.6-1.0 GeV/c (at T$_p$ >1 GeV) in the NN($^1S_0$) pairs in ^{3}He and acts as a filter for the d*($^1S_0$)+N configuration[7] in ^{3}He.

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16.2 pd and dd interactions

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There are several fundamental reasons for the interest in the deuteron as a beam and target. First, as a loosely bound np state it is the best approximation to the free neutron target. Second, the pd and dd interactions are indispensable as the testing ground for a few body interaction theories. Third, the high momentum transfer pd interactions at COSY and ed interactions at CEBAF are the complementary probes of the short distance properties of the deuteron. Fourth, as a spin-1 target with the substantial quadrupole spatial deformation the deuteron is a testing ground for theoretical ideas on the spin-orbit coupling in relativistic bound states which is of much relevance to the understanding of the spin properties of vector mesons produced in deep inelastic scattering at HERA. Fifth, the tensor polarization effects in pD and DD interactions are unique to the spin-1 deuteron, here the data from COSY will be complementary to the tensor polarization effects studied by the HERMES collaboration at DESY [1]. Some of the above aspects of the physics with the polarized deuterons at COSY have been discussed at this Workshop by Yu. Uzikov, R. Schleichert, V. Baru, F. Rathmann, A. Kacharawa, H.P. gen. Schieck, Ch. Elster and A. Kobushkin, see these Proceedings [2], the relativistic lightcone treatment of spin-orbit coupling in the vector mesons is found in [3], for the evaluation of tensor polarization effects in DIS off deuterons see [4]. Here I only want to comment on the use of the polarized deuteron as the polarized neutron target at COSY.

The principal issue is whether the pD elastic and breakup data admit a simple interpretation in terms of the pp and pn scattering amplitudes or not. To this end, the theoretical description of the pD scattering changes drastically form the low energy to intermediate and to the high energy of COSY. Specifically, at low energies only lowest partial wave contribute the the projectile-nucleon scattering and the projectile can rescatter many times back and forth between the proton and the neutron, see fig. 1b. Here we indicated only the subset of the Faddeev diagrams,

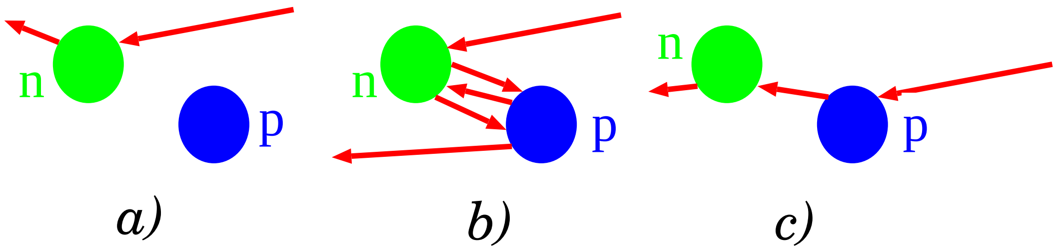

Figure 3: *The single-scattering/impulse approximation (fig. 1a) and multiple-rescattering diagrams for the matrix of interaction of projectile with the deuteron at low (fig. 1b) and high (fig. 1c) energies. The elastic scattering is obtained if the scattering matrix id sandwiched between the initial and final state deuteron wave functions, the deuteron breakup is obtained if the final state is a two-nucleon continuum with the appropriate NN final state interaction*

one must allow also for the nucleon-nucleon interaction between those rescatterings and needs to solve the very involved Faddeev equations. A very good summary of the relevant issues was presented at this Workshop by Pätz gen. Schieck and Elster. The high energy scattering is forward peaked and the multitude of multiple rescattering diagrams reduces to the double scattering when the two nucleons are aligned along the nearly straight-line trajectory of the projectile, see fig. 1c. The emerging formalism has become known as the Glauber theory, its most important feature is that the double scattering amplitude is calculable nearly parameter-free in terms of the projectile-proton and projectile-neutron scattering amplitudes. With the exception of very small excitation energies, the differential cross section of the breakup reactions is readily related to the free-nucleon cross section with calculable double-scattering corrections. A very instructive demonstration of how the full Faddeev calculations of the spin observables of the deuteron breakup tend to the free-nucleon scattering observables as the energy of the beam nucleons is increased from 65 MeV to 220 MeV is found in the review by Glöckle et al [5], the Glauber theory discussion of spin phenomena in the proton-deuteron elastic scattering has

been reported by Alberi et al. [6], who find a good agreement between the Glauber theory and the experimental data.

The overall conclusion is that the ineterpretation of the experimental data on the deuteron breakup at ANKE-COSY (for the discussion of the planned experiments see the talks of A. Kacharava, R. Schleichert and F. Rathmann [2]) in terms of the *np* elastic and charge exchange amplitudes will be fairly straightforward, and the COSY collaboration can contribute to the databse on polarized and unpolarized *np* scattering as much as EDDA-COSY collaboration did for the *pp* scattering.

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16.3 Lightest nuclei structure at short distances in exclusive reactions

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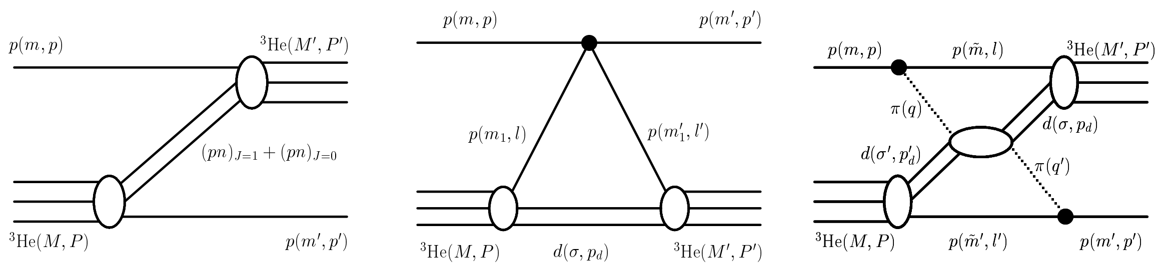

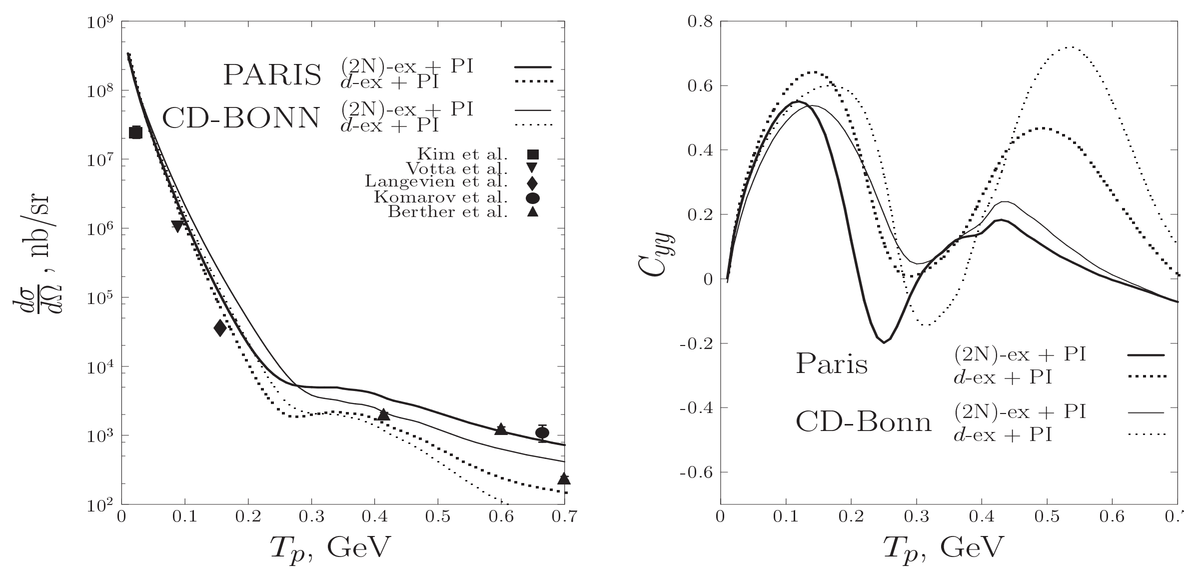

Exclusive backward (in the center of mass frame) proton-nucleus and deuteron-nucleus scattering at intermediate energy involves large momentum transfer and therefore such reactions can provide an access to the high momentum components of the wave function lightest nucleus (d, ^{3}He, ^{4}He). We discuss some important mechanisms of $p+^3$ He elastic scattering at $\theta = 180^0$, two-nucleon exchange (2N), the direct mechanism (DIR) and rescattering of intermediate pions (PI), and calculate the differential cross section and polarization transfer C_{yy}. We also consider appropriate mechanisms for $d+^3$ He and $d+^4$ He elastic backward scattering and

calculate energy dependence of the differential cross section and the tensor analyzing power T_{20} for this reactions. It is demonstrated that this observables strongly depend on $d+p$ and $d+d$ components of ^{3}He and ^{4}He wave functions, respectively. It is also discussed a problem of study $(2N)_{^1S_0}+N$ component of ^{3}He wave function in $n+^3$ He elastic backward scattering.

16.4 Double Spin-Observables for pn Systems in pd Interactions

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The nucleon-nucleon (NN) interaction represents one of the simplest and most fundamental systems involving the strong interaction. An appreciation of the (NN) interaction constitutes a necessary step towards a consistent understanding of the binding of neutrons and protons in nuclei, as well as giving an insight into reactions between nucleons (or nuclei) and nuclei and, most importantly, into the makeup of nuclear matter.

The complete description of the NN interaction requires precise data in order to carry out phase–shift analyses (PSA), from which the scattering amplitudes can be reconstructed. For this purpose one generally needs data from experiments where both the beam and target particles are polarised in the initial state, as well as polarisation determination of final state particles.

Experiments of this kind were carried out for the pp system to about 3.0 GeV (*R.Arndt et al., Phys. ReV. C62(2000)034005; EDDA Collaboration: Phys. ReV. Lett. 90(2003)142301.*)

The challenging physics goals of the proposed research program in frame of the ANKE collaboration comprise the following objectives:

1. Substantial and systematic enhancement of the world database of pn elastic

scattering through a series of high-precision experiments, using polarised protons quasi-elastically scattered off the polarised deuteron target ($\tilde{p}\tilde{d}$).
2. Measurement of the spin structure of the amplitudes of the elementary np charge-exchange (CE) process via deuteron-induced reactions ($\tilde{d}\tilde{p}$).
[http://www.fz-juelich.de/ikp/anke/doc/Proposals.html]

pn**: Elastic scattering observables**

Up to now, the world data base on elastic pn scattering is rather scarce (*F.Rathmann, W.T.H. Van Oers, and C.Wilkin, Intermediate Energy Spin Physics, Progress Report, 11/1998*); above about 1.1 GeV there exist practically no data. Within the proposed experiment it will become possible to substantially extend the pn data base into the unchartered territory up to 2.83 GeV incident proton energy. Polarisation data are the essential precondition for a partial wave analysis, because the existing low energy amplitudes can not be extrapolated to higher energies. Among the different polarisation observables, that can be measured, spin correlation parameters are most easily accessible. Their measurement requires a polarised beam incident on a polarised neutron (deuteron) target.

np**: Charge-Exchange break-up (CE)**

Information can be obtained on the spin–dependent np elastic amplitudes near the backward direction (the charge–exchange region) by measuring the charge–exchange breakup of polarised deuterons on an unpolarised hydrogen target (*D.Bugg, C.Wilkin, Nucl. Phys. A467(1987)575*). The effect can be understood qualitatively as follows. The two nucleons in the deuteron are in $T = 0$, $^3S_1$ or $^3D_1$. The spatial and spin states are symmetric so that, by the generalised Pauli principle, the isospin state is antisymmetric. In the charge–exchange reaction under special kinematic conditions (scattering angle θ close to zero and momentum transfer $t \sim 0$), the transition to a spin antisymmetric $^1S_0$ state of two protons therefore requires a spin flip. The overall intensity of the spin–dependent parts of the elementary $np \rightarrow pn$ CE amplitude can thus be inferred from the probability

of the dp CE process. The experimental programme is divided into two parts:

1. The first stage will utilise unpolarised and tensor polarised deuteron beams incident on an unpolarised hydrogen cluster target. The differential cross section gives the overall intensity of the spin–dependent parts of the elementary CE process. Tensor polarised deuteron beam enables us to separate the absolute values of three spin–dependent amplitudes.

2. Using transversely polarised deuterons incident on a polarised internal hydrogen gas target and measuring the spin–correlation coefficient opens the possibility of obtaining the relative phase between amplitudes.

Since we plan to measure the cross section in parallel with polarisation observables, our experiment will be the first that can provide complete data necessary to determine the spin-dependent part of the elementary np process in the energy range above LAMPF (800 MeV) up to maximum beam energy per nucleon (1150 MeV) achievable at COSY. ANKE spectrometer is sensitive to the angular range of $\theta_{c.m.} \approx 0^\circ - 30^\circ$, which is unchartered territory for the pn system.

The measurements will be carried out at the internal beam of the Cooler Synchrotron COSY using the magnetic spectrometer ANKE, including spectator detection system integrated into the complete experimental setup. Experiment will alow to calibrate for the first time the tensor (vector) polarisation of the COSY deuteron beam.

It should be noted, that on a worldwide scale the above outlined experimental program in a near future is possible only at COSY.

16.5 Nd Interaction at Low Energies: Open Questions

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Much emphasis in low-energy hadron research in the past has been on the three-nucleon system, being the simplest system beyond the two-nucleon system. The present situation and future of low-energy studies of the interaction of three nucleons is characterized by different trends.

One is the tremendous progress made by few-body theory, first, by numerically exact calculations using precision meson-exchange nucleon-nucleon potentials including different three-body forces and, recently, in applying realistic effective-field theory approaches to low-energy problems.

Both approaches have been highly successful in describing many few-body observables but still have been incapable of solving long-standing puzzles such as the A_y puzzle of p-d elastic scattering or the cross-section discrepancies in deuteron breakup. At low energies progress has been made in incorporating the Coulomb force into the Faddeev calculations thus giving the existing precise charged-particle data renewed importance as compared to neutron data.

Experimentally the number of low-energy working groups has decreased substantially in recent years, partly because accelerators were phased out or redirected towards other fields. Though the agreement between low-energy data for many observables is good, for a number of observables some long-standing completely unresolved discepancies persist:

- d+N elastic cross section (Sagara) anomaly
- d+N elastic A_y (and iT_{11}) puzzle
- d+N breakup anomaly in the space-star situation
- d+N breakup anomaly in the quasi-free scattering situation

The low-energy discrepancies decrease with energy in contrast to the behavior of newly discovered medium-energy discrepancies. This suggests that different three-body forces may be acting in these energy regions. One serious problem has been that on the one hand the number of n+d observables is smaller and data quality

partly not as good as that of the corresponding p+d data, on the other hand theory has made progress in incorporating the Coulomb force in the elastic scattering, but not yet in deuteron breakup.

Therefore besides new and innnovative theoretical efforts there is a need for more precise and also for new data to track down the origin of these discrepancies. In the elastic channel new polarization observables should be measured whereas for the breakup the exploration of much larger regions of the available phase space should be performed. Inclusion of the Coulomb force in the theory and exploitation of the higher precision and larger number of observables in the charged-particle channels would be necessary.

16.6 Questions and Problems in Few Body Reactions

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17 Closing Session

17.1 Summary I

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This was an exciting and stimulating meeting, both in terms of the physics opportunities available to be explored at COSY and eventually GSI and because the meeting was in large part organised by a very spirited group of young scientists who see the possibilities for an exciting scientific future at these facilities. I would like to extend my appreciation to these young people for doing a fine job.

One cannot look to the future without first appreciating the achievements of the past and COSY certainly has a string of achievements of which any laboratory would be proud. For example, together with its partners at IUCF and the Svedberg Lab in Uppsala, COSY has done a wonderful job of mapping the systematics of meson production near threshold in few nucleon systems. These precise measurements have stimulated a great deal of theoretical effort, using methods from χPT to somewhat older but effective meson exchange models. The studies of η and ω production are especially interesting for the information they yield as to whether predictions of possible meson-nucleus bound states are correct [1].

There is currently enormous interest in the problem of baryon spectroscopy. COSY has already produced important data on the Σ and Λ hyperons in the mass region around 1.4 GeV and in the future it will be extremely important to exploit the capabilities of COSY as a probe which is complementary to Jefferson Lab. Only a concerted effort involving theory and experiment working together from all possible angles will allow us to resolve the many puzzles we face in this field – puzzles such as “missing states”, exotics and so on. Here, as in most other aspects of the COSY program the lab can be proud of the support it has received from the theoretical

physics group, under the leadership of Josef Speth. Their work on the reaction mechanisms associated with the formation of various baryon resonances has led to new insights into the nature of these states [2]. It will be especially important, given the recent advances in our ability to calculate excited states in lattice QCD [3], to make use of the best of both approaches in analyzing new experimental data.

The recent discovery of the θ^+ [4], a strangeness +1 baryon whose minimal quark content is $uudd\bar{s}$, caused enormous excitement at the meeting. The remarkable precision with which it had been predicted was discussed in detail [5], along with the alternative explanations that had already appeared. It is quite clear that there is a very exciting program to be carried out at COSY as well as JLab and other facilities, to determine the properties of this state, especially its spin and parity, and to search for other exotic baryons which have been predicted. The existence of such exotic states opens a completely new chapter in the development of strong interaction physics and we all look forward to the discoveries of the next few years with great anticipation.

While on the topic of exotic states we note that theory group has also made important progress in the analysis of possible "molecular states" in the coupled $\pi\pi - K\bar{K}$ system [6]. Such states are also of tremendous interest as we struggle to solve non-perturbative QCD. This work is of direct relevance to recent discoveries of unexpected charmed mesons in $e^+ - e^-$ annihilation [7], as well as possible exotic mesons reported at BNL [8].

Of course, a number of new results from other laboratories were reported at the conference. We mention particularly the new results on charge symmetry violation from TRIUMF and IUCF. The former involved the first report of a non-zero forward-backward asymmetry in the reaction $n + p \to d + \pi^0$, while the latter involved a very clean signal made in the last weeks of operation of the Cooler. There is considerable theoretical interest in both results.

Finally, we should look to the future and apart from the examples already cited there were many other important research directions to be explored. Data on the behaviour of hadrons in dense matter obtained from heavy ion collisions requires

comparable data from proton and deuteron induced reactions where density related effects are not expected to be so large. This is particularly needed for K^+ and K^- mesons in matter [9]. One can also make and explore the properties of hypernuclei, produce the a_0 meson using various initial states (and therefore together with various nuclear final states), excite the Roper and other resonances with new projectiles and thus look for new insight into the structure of these resonances.

On top of the extensive program involving COSY for the next decade, FZ-Jülich also has the opportunity to play a major role in building and designing experiments for the new GSI facility. This facility, along with JHF in Japan and JLab in the USA, will provide the key platforms for unravelling the secrets of hadron physics over the next 20 years. It is a tremendous opportunity to be be a major partner in such a significant project from the very beginning and the enthousiasm shown at the workshop clearly demonstrated the willingness of the community to accept the challenge.

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17.2 Summary II

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From the experimental point of view, the aim of the workshop "Hadron Physics at COSY" was two-fold:

a) to obtain an overview of what has been achieved so far in hadron physics with different probes, and

b) to identify possible directions and - better - specific experiments which should be given a high priority in future measurements.

Due to time constraints and breadth of the field "hadron physics", it could not be expected to achieve a full overview, but certainly many important issues were covered and very recent (and exciting) results were presented.

As far as new experiments and future directions are concerned, the meeting was a very good starting point, which in the meantime seems to result in more specific developments like "WASA at COSY".